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RESULTS OF LYSIMETER EXPERIMENTS

A. DEMOLON AND E. BASTISSE

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Experiment stations in different countries have been using lysimeters for many years. These lysimeters differ from one another according to the contemplated research work. In many places it was deemed necessary to leave the soil *in situ* with its profile structure undisturbed; such a condition is indispensable for obtaining results which measure what really takes place in the field. Consequently the gauges may reach a depth of 2 m.

In our own researches we have used lysimeters to study a few processes related to pedogenesis under natural conditions. The tanks are waterproof cement boxes, 1 m. square and 0.6 m. deep. The dimensions of the boxes efficiently minimize the influence of the walls, and the square shape is favorable for seedlings. Three of the sides are in contact with the soil, the fourth is isolated by a layer of cork 6 cm. thick; samples can be taken at different depths through holes conveniently spaced.

EXPERIMENTS WITH LOAM

Each tank used in the loam experiments was filled in 1929 with 720 kgm• of an air-dried homogeneous soil consisting of the arable layer of a loam and having the composition shown in table 1. The tanks were left indisturbed for 2 years before observations were made. In 1931 we ascertained that all the tanks had become uniform and that the experimental error in the comparisons would be small enough to justify the conclusions drawn from the different treatments.

Drainage waters have been analyzed monthly, for the purpose of studying the balance of water and of the main mineral elements. Some lysimeters have been kept free from vegetation; others were cropped annually as follows: 1932, barley; 1933, carrots; 1934, wheat; 1935, oats; 1936, maize. Some of the tanks received special treatments, in duplicate, as follows: mulching (with paper), addition of organic matter (500 gm. straw per square meter in October), irrigation by porous pipes.

Loss of water

As a rule, no water drains through the tanks during summer, but water flows again at times during winter. Whether cropped or uncropped, tanks always showed the same drainage of water by the end of winter; therefore, each annual cycle was started March 1.

Under the climatic conditions of the region around Paris, drainage water results mostly from winter rains, which occur when nitrification is almost stopped and the biological activity of the soil is very low. In our tanks (the retention capacity of which is about 140 mm. of rainfall) a notable quantity of nitrates may escape leaching in dry years such as 1933 and be carried over to the next year.

On the other hand, the quantity of nonleached nitrates is lower than 10 kgm. per hectare and therefore not to be taken into account in years that average more than 200 mm. of rainfall during winter. Checking over the

TABLE 1

Composition of the loam in lysimeters at Versailles

(Parts per thousand air-dried soil)

PHYSICAL ANALYSIS		CHEMICAL ANALYSIS	
Coarse sand	20	CaO exchangeable	3.95
Fine sand	655	CaO carbonates	1.10
Silt	132	MgO exchangeable	0.25
Clay	136	K_2O exchangeable	0.09
Calcareous	2	N total	1.80
Organic matter	28	P_2O_5 available	0.15
Humus	11	C total	10.40

TABLE 2

Effect of cropping on evaporation and drainage of rainfall from lysimeters

	1932		1933		1934		1935		1936		AVERAGE	
	Uncropped	Cropped	Uncropped	Cropped	Uncropped	Cropped	Uncropped	Cropped	Uncropped	Cropped	Uncropped	Cropped
Rainfall, *mm.*	505.4	505.4	398.9	398.9	665.9	665.9	732.4	732.4	656.4	656.4	591.8	591.8
Drainage, *per cent*	39.6	23.7	27.4	15.2	39.2	33.5	42.7	34.8	46.7	35.1	40.2	30.0
Evaporation, *per cent*	60.4	76.3	72.6	84.8	60.8	66.5	57.3	65.2	53.3	64.9	59.8	70.0

results of a series of properly selected years made possible the tabulation of the data into a closed cycle, in such a way that the state at the end of the experiment duplicated that at the beginning. From such a closed cycle reliable information as to the translocation of soluble salts could be obtained.

The difficulty of obtaining experimental results on evaporation that are representative of the phenomena taking place in the field is well known. In the lysimeter the deep layers of the soil are eliminated, but in many investigations under wet climatic conditions the influence of these layers is of little importance. Table 2 gives our observations for the last 5 years, which may be regarded as including the extremes for northern France.

The annual evaporation from uncultivated land averages 59.8 per cent, ranging from 53.3 to 72.6 per cent. Cropped land evaporated, on the average, approximatively 17 per cent more water (corresponding to 60 mm.) than did fallow land. It is evident that this supplementary loss is much smaller than the loss due to transpiration. This fact corroborates our knowledge of the "shading effect" of vegetation, which reduces evaporation from the soil itself.

Loss of mineral constituents

Table 3 shows the average annual loss of the principal minerals and nitrogen for 5 successive years.

Except for P and K (the loss of which is almost entirely accounted for by the crops), it has been noted that crops have always lowered the losses of minerals from the soil; this is particularly true for CaO. Under the climatic conditions of northern France, loss of calcium is intensified in fallow soils, because leaching is increased. Fertilization can modify this. The annual

TABLE 3

Average annual loss of mineral constituents

(Kilograms per hectare)

	UNCROPPED	CROPPED			B − A
	Drainage (A)	Drainage	Crops	Total (B)	
CaO	553.6	357.8	23.9	381.7	−171.9
MgO	48.4	31.5	10.7	42.2	−6.2
K_2O	12.7	6.9	79.0	85.9	+73.2
N	168.2	82.1	59.3	141.4	−26.8
S	86.7	71.9	10.0	81.9	−4.8
P_2O_5	0.35	0.22	31.5	31.72	+31.3

addition to the lysimeters of 12.5 kgm. of artificial manure per square meter increased the loss of CaO through drainage by 23 per cent (132 kgm. CaO per hectare).

In tanks where the soil was uncropped, the ratio MgO/CaO in drainage water was more or less constant (1/8), the ratio between exchangeable Mg and exchangeable Ca in soil being 1/12. In tanks with crops this ratio increased because plants contain more magnesium than calcium.

Loss of nitrogen

In fallow soils 1.30 per cent of the nitrogen reserve in the soil (1.80 parts per thousand) is nitrified each year on the average, which amounts to 84 kgm. per hectare for a 0.3-m. layer, variations depending on the climatic characteristics of any particular year. Cropping decreased the nitrogen loss (crops + drainage) by 16 per cent. This fact has already been observed by Deherain (1), by Warrington (8), by Russell (6), and by Lyon (3). The decrease may be due to a decrease in the formation of nitrates or to an increase

in the utilization of nitrates formed. The second hypothesis is favored by the following observations:

The effect of cropping on nitrogen removal was observed in tanks which were provided with subterranean irrigation in dry seasons or which had been mulched. The decrease of nitrates is not correlated, therefore, with an inhibition of nitrification by the drying of the soil as a consequence of cropping.

If nitrogen reserves were really spared in the cropped tanks, these lysimeters, in the course of time, should reach a higher level of nitrified nitrogen than the uncropped ones, a situation which has not been observed as yet.

From data in table 3 we see that the diminution of the calcium salts removed by the tanks without crops (171.9 kgm. CaO) corresponds to the difference in the removal of nitrates by drainage [168.2 − 82.1 = 86.1 kgm. N, corresponding to 172 kgm. CaO as $Ca(NO_3)_2$], which favors the conclusion that the biological activity has been the same in both cases.

Nitrate accumulation decreased only during the first year in the lysimeters that received straw; the added organic matter slowly but progressively nitrifying as shown in table 4.

In short, we believe that cropping results in the consumption of a certain quantity of nitrates in addition to the quantity used up for the nutrition of the plants, as a result of an increased activity of microbes on the soil, which

TABLE 4

Influence of straw on nitrate formation in an uncropped soil

TREATMENT	1933	1934	1935	1936
No straw	100	100	100	100
Straw added, 500 gm. per square meter annually	93.3	99.6	107	114.6

may be due to easily decomposable non-nitrogenous organic matter. This view is supported by the fact that in pot cultures the coefficient of nitrate utilization is always less than 100 per cent.

WEATHERING OF GRANITE

In lysimeter experiments on the weathering of granite, each tank was filled with 800 kgm. of granite rock[1] that had previously been crushed and sifted into pieces ranging from 2 to 4 mm. in diameter. The drainage water, which was always clear, was periodically collected, measured, and analyzed. The change in the granite was observed after 5 years' exposure to natural conditions without vegetation.

Mechanical analysis of weathered granite

Mineral colloids were extracted, without acid pretreatment, by the following dispersion method, which induces the least alteration (5):

Destruction of organic matter by hydrogen peroxide.
Washing with 0.1 *N* KCl to eliminate the soluble Ca salts.
Peptization in the presence of Na_2CO_3 (concentration 5 m.e. per liter).

[1] Composed of quartz, orthoclase, muscovite, and biotite.

The separation of the fine particles was then made as usually by settling and decantation.

The whole mass contained approximatively equal amounts of the three fractions, 1–2 mm., 0.2–1 mm., and less than 0.2 mm. Particles representing the clay fraction ($<2\ \mu$) amount to 0.8 per cent, uniformly distributed from top to bottom of the lysimeter (2). The disintegration of granite, therefore, proceeded evenly in the whole mass, without expenditure of mechanical energy for the translocation of materials, and solely as a result of climatic factors (rain, temperature). No migration of the smallest particles occurred. It has been noted, moreover, that below 200μ the separation of the mineral species was more or less complete.

TABLE 5

Chemical analyses of original granite, of weathered granite, and of two natural clays

	ORIGINAL GRANITE	WEATHERED GRANITE			GRANITIC SOIL B HORIZON	BRICK EARTH B HORIZON
		Silt	Clay			
		$20-2\mu$	$2-0.75\mu$	$<0.75\mu$		
SiO_2 ..... *per cent*	74.75	69.43	60.72	55.61	42.40	48.90
Al_2O_3 ..... *per cent*	13.50	15.95	21.59	22.98	31.05	25.40
Fe_2O_3 ..... *per cent*	1.50	2.22	2.70	2.82	7.85	8.70
TiO_2 ..... *per cent*	.....	.....	.....	0.50	0.64	0.86
CaO ..... *per cent*	0.93	0.98	0.99	1.12	0.30	0.22
MgO ..... *per cent*	0.59	0.93	1.46	2.03	0.51	1.26
K_2O ..... *per cent*	4.63	4.65	4.50	4.63	3.21	2.70
H_2O ..... *per cent*	0.90	2.10	4.06	7.54	10.95	9.77
Total ..... *per cent*	.....	.....	96.02	96.73	96.27	96.95
SiO_2/R_2O_3	8.78	6.64	4.40	3.87	2.00	2.67
Base-exchange capacity ..... *m.e.*	.....	.....	61.00	67.00	81.00	82.00

Chemical analysis of different fractions

Organic matter must be thoroughly destroyed before chemical analyses are made, otherwise the results of studies on colloids are meaningless. Results of the chemical analyses of the original granite and of the different fractions of the weathered granite are given in table 5.

The analyses of different fractions show that chemical changes occur only in particles less than 200μ. As the size of particles diminishes, the relative importance of SiO_2 decreases and that of sesquioxides and water of hydration continuously increases. As far as the bases are concerned, the percentages of CaO and K_2O are very low, but MgO increases markedly as the size of particles decreases. We must, therefore, conclude that biotite, more or more or less chlorinated, accumulates within the clay.

Comparison of the weathered granite with the original granite does not show the exact changes in the various elements; granite compounds (quartz, feldspar, mica) contribute unequally to the formation of colloidal fractions.

On the other hand, analysis of drainage water shows the importance of losses through leaching.

Analysis of leachates

During the 5 years under consideration, the rainfall totaled 2.806 mm., of which approximately 40 per cent, or 1.159 mm., was recovered as drainage water. Table 6 shows the mineral losses due to leaching.

Considering that 6.48 kgm. of clay was being formed and taking into account the elements which were adsorbed by these colloids, we can assume that SiO_2 and K_2O released from the rock represent only a very small part of the quantity corresponding to a theoretical formation of clay:

$$6\ SiO_2 \cdot Al_2O_3 \cdot K_2O + 2H_2O = 4SiO_2 + K_2O + 2SiO_2 \cdot Al_2O_3 \cdot 2H_2O$$

The relative order of leaching out of basic material is as follows: $CaO > K_2O > MgO$, but MgO comes before K_2O if we consider the percentage of the whole quantity existing. The mass was not acidified below pH 6.85.

TABLE 6

Losses of mineral substances in 1 square meter lysimeter containing 800 kgm. granite during a 5-year period (1931–1935)

	TOTAL	PER CENT
	gm.	
Dry matter	387.3	....
After ignition	306.5	....
CaO	89.0	1.19
MgO	18.4	0.39
K_2O	31.0	0.08
SiO_2	19.7	0.003
S of sulfates	24.0	4.85
N of nitrates	4.8	4.85

The bases are leached out principally in the form of nitrates and sulfates. Silico-gel plates have shown that nitrifying organism rapidly colonize the mass. Moreover, it has been noted that the quantity of nitrogen as determined by analysis is almost equal to that which might have been contributed by rainfall during the 5-year period. Most of the sulfates result from the oxidation of sulfur present in the original granite (0.62 parts per thousand).

The fact that the ratio SiO_2/K_2O is close to 1 may signify that silica and potassium are washed out in the form of potassium silicate.

Finally, we can conclude that dissolution and hydrolysis, generally considered as fundamental processes, have contributed very little to the production of clay colloids. In this initial phase of weathering the phenomenon of hydration must be considered as prominent.

Examination of clay colloids

The two fractions 2–0.75μ and $<0.75\mu$ were studied separately, and the colloids in these fractions were compared with those extracted from the B

horizon of two soils, one formed from the same parent rock and the other from a brick earth. The results are shown in table 5.

A comparison of the composition of these samples gives a measure of the extent to which chemical weathering has proceeded. In the newly formed clay, weathering increases gradually as the particles become finer. Moreover, we must note that the percentage of SiO_2, the ratio SiO_2/R_2O_3, and the percentages of nonexchangeable bases (CaO, MgO, K_2O) are higher in this immature clay than are those in the older soils. Titania has a tendency to accumulate with iron in the clay fraction. These considerations suggest an analogy between our juvenile clay and clays from glacial loams studied by O. Tamm.

From a physicochemical point of view, our juvenile clay displays every property common to clay colloids. Particularly, it behaves as a hydrophilic suspensoid and is sensitive to coagulating agents. The fixation capacity of bases is very similar to that of older clays, chiefly of the finest fraction.

This experiment gives us a view of the first stage of clay genesis in the weathering of granite under our climatic conditions. It shows that in a roughly comminuted mass, clay colloids are formed very early by a hydration process which preserves an important part of the combined bases. On this point, our observations agree with the conclusion of Zemiatchensky (9) concerning the transformation of feldspar in hydro-micas.

It should be added that we know of the existence of clays in which the phenomena of chemical alterations are weak (7, 9). We must, therefore, consider that Mattson's (4, 5) theory of clay formation by way of mutual precipitations of different colloids is correlated with secondary processes which take place in a more advanced stage.

These observations are also in agreement with the conception that the clay micelle is heterogeneous and is composed of a silicate core surrounded by a colloidal coating. It is easy to understand, thus, that clay can have a crystalline character, that it varies in its chemical composition, and that it is capable of evolution in soils under the influence of weathering.

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THE LEACHING ACTION OF RAIN WATER UPON DOLOMITE AND LIMESTONE SEPARATES INCORPORATED WITH QUARTZ IN OUTDOOR LYSIMETERS

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Dolomite is used most extensively in the Coastal Plain, where many soils are made up of preponderant proportions of quartz and relatively small quantities of acidoids. Since many soils of such character have limited capacity to decompose added dolomite and to fix the calcium and the magnesium supplied thereby, direct solvent action upon the added raw dolomite may then supply nutritive calcium and magnesium.

A study was therefore made of the composition of rainwater percolations from chemically equivalent separates of limestone and of dolomite, incorporated in quartz. In such systems the factor of the behavior of the complexes formed by fixation of added calcium and magnesium is eliminated, and the influence of soil flora is at a minimal and near-constant level. The solvent action of rapid percolations in the readily permeated quartz medium would be expected to be less than the dissolving action of the more slowly moving percolates from sandy soils in which normal biological activities occur. The amounts of calcium and of magnesium removed from the quartz systems by rainwaters should be indicative, however, of the presumably more extensive solvent action within soil systems of high quartz content.

MATERIALS AND TREATMENTS

All values used in the designation of rates of treatment and of quantities of calcium and of magnesium leached are in terms of calcium carbonate. Washed 20–40-mesh and 60–100-mesh separates of limestone and of dolomite were used in lysimeters having a surface area of 1/20,000 acre. The analyses of the limestone and of the dolomite separates are given in table 1. The two limestone separates had a common $CaCO_3$-equivalent value of 99.76 per cent and contained 0.94 per cent of $MgCO_3$. The dolomitic limestone contained calcium and magnesium carbonates in the approximate ratio of 51 to 38. The $CaCO_3$-equivalence of the 60–100-mesh dolomite separate was 96.7 and that of the 20–40-mesh separate was 94.5.

The limestone and the dolomite incorporations were made at the rates of 2, 13.3, and 53.1 tons per 2,000,000 pounds of quartz. Each treatment was incorporated only in the upper half of its quartz medium, although all percola-

tions were from the full depth of quartz. Within the zone of contact between quartz and incorporations, the several rates of treatment were therefore twice those respectively stipulated for the 100-pound charges of quartz. The upper zone of treatment and the lower untreated zone were separated by means of galvanized iron, asphaltum-coated, wire-cloth discs. The two larger incorporations were respectively equivalent to rates of 8 tons and 32 tons of CaO, these two rates having been used for additions of seven liming materials in a related earlier lysimeter study of a heavy type of soil.

The mixtures were placed in the 1/20,000-acre tanks June 20, 1931. The leachings from successive annual rainfalls of 44.12, 56.40, 49.61, and 55.34 inches were collected for the following 4-year period and analyzed for calcium, magnesium, dissolved carbonates, and sulfates. Quartz controls were placed

TABLE 1

Analysis of separates of limestone and of dolomite incorporated in the quartz medium of the outdoor lysimeters

	LIMESTONE*	DOLOMITE†	
		20–40 mesh	60–100 mesh
	per cent	*per cent*	*per cent*
Insoluble matter	0.25	11.26	9.14
$Fe_2O_3 + Al_2O_3$	0.23	0.80	0.80
Ca, as $CaCO_3$	98.64	49.71	51.83
Mg, as $MgCO_3$	0.94	37.63	37.72
Total analyzed	100.06	99.40	99.49
Mg, as $CaCO_3$-equivalent	1.12	44.80	44.90
Ca + Mg, as $CaCO_3$-equivalent	99.76	94.51	96.73

* Purity of limestone assured uniformity in composition of different separates.

† A kiln-dried product containing small quantities of coal dust.

at each end of the row of lysimeters to collect rainwaters, so that the respective increments from quartz only could be determined.

LEACHATE VOLUMES

The individual leachates for the annual periods and for the 4-year period are given in table 2. Frequency of rainwater collections was governed by the periodicity of each annual rainfall. From June to June, there were 8 collections in 1931–32, 7 in 1932–33, 6 in 1933–34, and 6 in 1934–35.

The mean of the volumes that passed through the quartz controls was practically identical with the mean of the volumes that passed through the units that contained the minimal additions of limestone and of dolomite. Likewise, the 13-ton additions caused no appreciable difference in the amounts of water leached from the constant amount of quartz. There was, however, a definite diminution in the leachate volumes from the four treatments at the 53-ton

rate. This was noted in each of the 16 comparisons and is attributed to increased bulk rather than to physical change in the quartz in contact with the much larger incorporations of the two limestones.

TABLE 2

Leachates from limestone and dolomite in quartz media

Leachates expressed in kiloliters

LIMESTONE INCORPORATIONS			LEACHATES				
Type	Mesh*	Ton rate†	1931–32	1932–33	1933–34	1934–35	4-year average
Calcic	20–40	2	217	259	223	241	235
	"	13.3	215	256	223	241	234
	"	53.1	213	253	218	236	230
	60–100	2	215	259	225	242	233
	"	13.3	212	252	218	239	231
	"	53.1	204	236	203	223	217
Dolomitic	20–40	2	213	253	220	237	231
	"	13.3	212	251	221	238	231
	"	53.1	210	247	217	235	227
	60–100	2	211	250	221	239	230
	"	13.3	211	248	215	233	227
	"	53.1	202	233	198	221	214
Sand blank, north end‡		0	218	255	237	243	238
Sand blank, south end		0	214	252	219	237	231

* Separates were washed before incorporation.

† Tons per 2,000,000 pounds of quartz.

‡ For collection of rainwater at each end of the row of lysimeters.

COMPOSITION OF LEACHATES

Calcium content

The data of table 3 represent the $CaCO_3$-equivalence of the calcium brought by rainwaters, supplemented by that dissolved in the upper zone and carried therefrom through the underlying zone of untreated quartz. The calcium content of rainwaters collected at a given point has been found to vary appreciably with season (7) and with the location of the tanks within a relatively small radius. The calcium content of rainwaters collected within a city will exceed that of collections made in adjacent rural sections. Waters collected in gauges and in blank lysimeters nearer the roadway invariably have a calcium content greater than that found in collections obtained in the more distant receptacles. A mean annual calcium increment of 161 pounds passed through the quartz controls at the north end of the installation, as against 136 pounds

for the more remote controls at the south end. The mean value of 149 pounds was used in correcting the total calcium outgo to determine the amounts actually derived from the limestone and the dolomite.

Magnitude of treatment was reflected in each of the 16 comparisons of annual outgo of calcium from both types of limestone, but the relationship between rate of addition and amounts leached was not proportionate. The total amounts of calcium derived solely from the 13-ton and 53-ton high-calcic

TABLE 3

Calcium outgo in outdoor lysimeter leachings from limestone and dolomite incorporated in quartz medium

Outgo expressed in pounds of $CaCO_3$-equivalence per 2,000,000 pounds of quartz medium

LIMESTONE INCORPORATIONS WITH QUARTZ			OUTGO						
								Mean Annual	
Type	Mesh*	Ton rate†	1931–32	1932–33	1933–34	1934–35	Total	Actual	Corrected for blanks
Calcic	20–40	2	233.6	266.8	239.5	250.2	990	248	99
	"	13.3	294.4	361.3	295.4	337.6	1,288	322	173
	"	53.1	371.6	435.0	341.4	398.2	1,546	387	238
	60–100	2	212.2	281.6	226.7	246.1	967	242	93
	"	13.3	355.3	404.1	329.9	371.2	1,461	365	216
	"	53.1	433.4	465.4	354.3	443.0	1,696	424	275
Dolomitic	20–40	2	165.2	188.4	195.9	199.9	749	187	38
	"	13.3	223.2	255.6	238.1	242.5	959	240	91
	"	53.1	293.6	320.4	257.5	285.6	1,157	289	140
	60–100	2	176.8	184.9	184.2	180.1	726	187	33
	"	13.3	302.6	307.5	250.3	265.0	1,125	281	132
	"	53.1	386.9	386.6	313.6	364.1	1,451	363	214
Quartz blank, north end‡		0	156.4	162.0	176.8	148.6	644	161	...
Quartz blank, south end		0	129.0	121.2	153.5	140.2	544	136	...

* Separates were washed before incorporation.

† Tons per 2,000,000 pounds of quartz.

‡ For collection of rainwater at each end of the row of lysimeters.

limestone treatments were only 2.1 times and 2.6 times the corrected total calcium outgo from the 2-ton treatment. The total amounts of calcium derived solely from the 13-ton and 53-ton dolomite treatments were 3.1 and 4.9 times the amount of calcium actually leached from the 2-ton dolomite addition.

Comparable amounts of calcium were leached from the 20–40-mesh and 60–100-mesh separates of limestone at the 2-ton rate. This was true also of

the less extensive amounts of calcium leached from the 2-ton incorporations of the two corresponding dolomite separates.

The 96-pound mean annual net loss of calcium from the 2-ton incorporations of the two limestone separates exceeded the 70-pound increase in annual outgo from a 3,570-pound $CaCO_3$-equivalent addition of 100-mesh limestone to the upper zone of a black Onslow sandy soil at the Virginia Station (3, p. 13). When incorporated to full depth in the same black soil, the 3,570-pound limestone treatment caused an increase of 124 pounds in the calcium outgo. The corresponding surface and full-depth 3,570-pound incorporations of dolomite in the black Virginia soil caused annual increases in calcium outgo of only 11 and 8 pounds, respectively. When additions beyond fixation-capacity are made, the undecomposed dolomite and the fixed calcium and magnesium produce divergent proportions of dissolved calcium and magnesium in the soil system (2).

The effect of fineness was definitely registered by the composition of the leachates from the two heavier additions. Every annual outgo of calcium from the 60–100-mesh limestone additions at the 13-ton and 53-ton rates, exceeded the corresponding annual outgo from the corresponding incorporation of the 20–40-mesh material. This was true also for the analogous comparisons for calcium outgo from the finer and coarser dolomite separates. In each of the six comparisons of calcium actually derived from the limestone and dolomite separates, the limestone separate yielded the larger quantity of calcium. The mean of the amounts of calcium derived from the six limestone separates was twice the mean of amounts actually leached from the six separates of dolomite.

Magnesium content

The quantities of magnesium leached from the separates of limestone and of dolomite are given in table 4. As would be expected, the meager magnesium carbonate content of the limestone did not yield an appreciable quantity of magnesium to the leachates. Moreover, the dominance of calcium carbonate caused an invariable diminution in the magnesium content of the rainwaters during their percolation through the limestone-quartz systems, the amount of magnesium leached from each of the six limestone additions being less than the magnesium content of the rainwaters. A similar phenomenon has also been noted as the characteristic effect produced upon the outgo of magnesium from native noncarbonate forms in soils that received *full-depth* incorporations of high-calcic liming materials (2, 3, 5, 6).

Each dolomite addition induced an increased outgo of magnesium, the increases being in the order of rate of addition. Magnesium outgo and rate of dolomite addition were, however, not proportionate. The mean net amounts of magnesium leached from the two 13-ton and the two 53-ton dolomite separates were, respectively, 2.5 and 4.1 times the net amount leached from the two 2-ton additions.

The influence of fineness of the dolomitic separates upon the amounts of magnesium leached was definite, although not extensive. The 60–100-mesh separate yielded more magnesium than did the 20–40-mesh material. This held for each of the three rates.

The differences between the outgo of the magnesium content of the raw dolomite and the outgo of the magnesium in the complex derived from added dolomite are apparent from a comparison of the leachates from the 2-ton addition of 60–100-mesh dolomite in the quartz medium and 3,570-pound $CaCO_3$-

TABLE 4

Magnesium outgo in outdoor lysimeter leachings from limestone and dolomite incorporated in quartz medium

Outgo expressed in pounds $CaCO_3$-equivalence per 2,000,000 pounds of quartz medium

LIMESTONE INCORPORATIONS WITH QUARTZ			OUTGO						
Type	Mesh*	Ton rate†	1931–32	1932–33	1933–34	1934–35	Total	Mean annual: Actual	Mean annual: Corrected for blanks
Calcic	20–40	2	28.7	44.5	24.5	23.3	121.0	30.3	−6.2
	"	13.3	28.5	33.9	19.6	20.2	102.2	25.6	−13.5
	"	53.1	22.6	25.7	21.1	18.7	98.1	24.5	−12.0
	60–100	2	28.4	45.6	19.8	23.4	117.2	29.3	−7.2
	"	13.3	28.9	37.7	21.1	20.0	107.7	26.9	−9.6
	"	53.1	30.5	37.4	21.5	20.7	110.1	27.5	−9.0
Dolomitic	20–40	2	36.6	68.0	34.9	51.3	190.8	47.7	11.2
	"	13.3	57.0	90.7	56.6	72.4	276.7	69.2	32.7
	"	53.1	85.2	101.4	70.8	79.7	337.1	84.3	47.8
	60–100	2	41.9	69.3	42.9	62.1	216.2	54.1	17.6
	"	13.3	69.8	94.1	59.7	77.0	300.6	75.2	38.7
	"	53.1	122.1	124.4	84.7	97.6	428.8	107.2	70.7
Quartz blank, north end‡		0	31.7	54.0	28.2	33.1	147.0	36.8	.....
Quartz blank, south end		0	29.2	50.0	30.9	34.5	144.6	36.2	.....

* Separates were washed before incorporation.

† Tons per 2,000,000 pounds of quartz.

‡ For collection of rainwater at each end of the row of lysimeters.

equivalent incorporations of similar dolomite of 100-mesh fineness in the black sandy soil used in the Virginia Station studies (3, p. 21). A net loss of only 17.6 pounds was registered as an annual outgo from the dolomite-quartz systems, whereas corresponding annual net losses of 78 and 89 pounds were found for the surface-zone and full-depth incorporations of the 3,570-pound additions of dolomite to the fallow Virginia soil. This difference is also partly attributable to the presumably higher H_2CO_3 concentrations that prevailed in the Virginia soil.

Total calcium plus magnesium

Table 5 shows the total quantities of Ca + Mg leached from the high-calcic limestone that contained only 0.94 per cent magnesium carbonate and from the dolomite that contained 52 per cent calcium carbonate and 38 per cent magnesium carbonate. The greater solubility of the high-calcic limestone was reflected by the fact that, for each of the three rates, the total Ca + Mg

TABLE 5

Total Ca + Mg and carbonates leached by rainwater during a 4-year period from limestone and dolomite separates incorporated in quartz medium in outdoor lysimeters

Outgo expressed in pounds $CaCO_3$-equivalence per 2,000,000 pounds of soil

LIMESTONE INCORPORATIONS WITH QUARTZ			OUTGO OF Ca + Mg						
Type	Mesh*	Ton rate†	4-year period		Mean of annual				Proportion accounted for by carbonates
			Total	As carbonate	Actual	Net‡	As carbonate		
							Actual	Net‡	
									per cent
Calcic	20–40	2.0	1,111	1,101	278	93	275	90	97
	"	13.3	1,390	1,377	348	163	344	159	98
	"	53.1	1,644	1,572	411	226	393	208	92
	60–100	2.0	1,084	1,094	271	86	274	89	100+
	"	13.3	1,569	1,527	392	207	382	197	95
	"	53.1	1,806	1,730	452	267	433	248	93
Dolomitic	20–40	2.0	940	956	235	50	239	54	100+
	"	13.3	1,236	1,141	309	124	285	100	81
	"	53.1	1,494	1,377	374	189	344	159	84
	60–100	2.0	942	942	236	51	236	51	100
	"	13.3	1,426	1,342	357	172	336	151	88
	"	53.1	1,880	1,666	470	285	417	232	81
Quartz blank, north end§		0	791	816	198	...	204	...	..
Quartz blank, south end		0	689	661	172	...	165	...	..

* Separates and quartz washed before incorporation.

† Tons per 2,000,000 pounds of quartz.

‡ Amounts derived from limestone or from dolomite; difference between outgo from quartz-limestone, quartz-dolomite units and rainwater leachings through quartz blanks.

§ For collection of rainwater at each end of the row of lysimeters.

leached from each limestone separate exceeded the Ca + Mg outgo from the corresponding dolomite separate. The mean of the total amounts of Ca + Mg carried by the rainwaters that passed through the six limestone incorporations was 1,436 pounds for the 4-year period, as against 1,320 pounds for the six dolomite incorporations. The mean total amounts of Ca + Mg actually derived from the six incorporations of limestone and of dolomite during the

4-year period, however, were only 696 pounds and 580 pounds $CaCO_3$-equivalence, respectively, or mean annual losses of 174 pounds and 145 pounds. The net losses indicate that the limestone was 1.2 times as soluble as the dolomite. When the same limestone and the same dolomite were extracted by six successive daily digestions with carbonated water, the solubility of the high-calcic limestone was found to be 2.48 times that of the dolomite (1). The true relationship between the solubility of limestone and that of dolomite in the rainwater leachates is masked, however, by the effect of the calcite content of the dolomitic limestone. Previous studies have shown that this particular dolomitic limestone contains 8–10 per cent of calcite in the interstices between the crystals of true dolomite. It has been noted that the intersticial calcite is dissolved faster than the dolomite (4). When the earlier extractions are filtered from the suspended rock, they therefore contain more calcium than magnesium, but successive subsequent extractions of the less soluble dolomite fraction bring calcium and magnesium into solution at the constant ratio of 1:1 (4).

The limestone and the dolomite of the present study were also used in the Virginia Station studies, which afforded comparative data as to the 4-year outgo of Ca + Mg induced by an annual rainfall of 33.8 inches, (3, p. 25). A net outgo of only 123 pounds of Ca + Mg was induced by the full-depth incorporation of a 3,570-pound $CaCO_3$-equivalence of high-calcic limestone in Onslow fine sandy loam, as against 72 pounds from surface-zone incorporation of limestone. The corresponding full-depth incorporation of dolomite gave a net Ca + Mg outgo of 97 pounds, whereas the surface-zone incorporation of dolomite gave a net Ca + Mg outgo of only 89 pounds.

Calcium:magnesium ratios

It has been pointed out that the ratio of Ca:Mg in the carbonated water extracts of true dolomite, as well as that of dolomitic limestones, is different from the one that holds for the composition of the respective leachates from high-calcic and dolomitic incorporations, subsequent to their fixation in soils. Moreover, the Ca + Mg from many dolomite fixations will either equal or exceed the Ca + Mg outgo from equivalent fixations from limestone treatments (3, 5, 6). The ratios of Ca to Mg in the rainwaters and in the leachates from the several dolomite separates can be seen by comparisons of the data of tables 3 and 4.

The Ca:Mg ratio in the rainwater percolates was 4:1. This proportion of magnesium is less than that found for previous directly collected rainwaters (7). The Ca:Mg ratio reported in the joint study (3, p. 12–21) were 2.12:1 and 1.82:1, respectively, for the Virginia and Tennessee Stations.

The 4:1 ratio of the rainwater percolates was altered in each of the six collections of percolates from the dolomite separates. After deduction of the calcium content of the rainwater percolates, the mean annual outgo of $CaCO_3$-

equivalence from the six dolomite separates was 108 pounds. A similar deduction for magnesium showed the mean annual outgo of 36.5 pounds as the $CaCO_3$-equivalence of the magnesium derived from the dolomite separates. These two values give a Ca:Mg ratio of 2.96:1. The proportion of Ca in this ratio is accentuated by the high proportion of calcium in the rainwaters and in the leachates from the calcite content of the dolomitic limestone, when only a small fraction of total charge of the latter is dissolved. As a cumulative effect—one not within the limited scope of the dissolving action of the rainwater upon the incorporations of dolomite in the quartz—the calcite passes more rapidly than the true dolomite, after which the Ca:Mg ratio in the leachates becomes stable, 1:1 (4). This indicates that the proportion of calcium in the early leachings from additions of dolomite in very sandy soils will be greater than that in the subsequent leachings.

Carbonate proportions

Differing from rainwaters collected directly in standard rain gauges and in control lysimeters (3, 7), the rainwater leachates that passed through the ground quartz controls contained carbonates substantially equivalent to their Ca + Mg contents. Moreover, more than 90 per cent of the net outgo of Ca + Mg from each of the six limestone incorporations was accounted for by dissolved carbonates. The net Ca + Mg outgo from the 2-ton incorporations of dolomite was attributable to carbonates, which also accounted for more than 80 per cent of the Ca + Mg outgo from each of the four heavier treatments.

It has been observed that the sulfate content of rainwaters may vary markedly within a restricted area in which variable quantities of sulfur gases and sulfates are expelled to the atmosphere, especially where soft coal is used. Previous studies (7) have shown that the sulfur contents of rainwaters collected in gauges adjacent to the lysimeters of the present experiment are due chiefly to sulfates of calcium and magnesium, with a minor quantity attributable to sulfate of potassium. The entire sulfate contents of the rainwaters from the quartz blanks were computed, however, to the $CaCO_3$-equivalent values given in table 6. Each annual sulfate outgo from the control near the road exceeded the corresponding outgo from the more distant control. The same relationship held for the amounts of calcium, magnesium, and carbonates, as shown, respectively, in tables 3, 4, and 5.

No unqualified explanation can be advanced for the lower proportions of carbonates in the leachates from the heavier treatments of dolomite. Greater reactivity between magnesic components and hydrated SiO_2, occurring as films upon the extensive quartz surface, may have been partly responsible for the lower proportions of carbonates found in the leachates from the two heavier dolomite treatments.

An exact balance between total outgo of Ca + Mg and those reactions accounted for jointly by sulfates and carbonates is difficult to obtain, because

of the inherent error encountered in titrations of dilute solutions of carbonates and the magnification of that error when analytical values are computed to terms of pounds per 2,000,000 pounds of the quartz medium. The error incident to the titration of dissolved carbonates is a plus value and one that is proportionately larger in the titrations of the smaller quantities of carbonates carried by the leachates from the minimal rate of 2 tons. The sulfate incidence is, however, as nearly constant as experimental conditions would admit, and the magnitude of the differences between the several values for calcium, magnesium, and Ca + Mg, demonstrate the influence of the three variables, particle size, rate of treatment, and differential solubilities of the two types of limestone.

TABLE 6

Ca + Mg attributable to sulfates in the rainwater leachates from the quartz blanks

Leachate contents expressed in pounds per 2,000,000 pounds of quartz

ANNUAL PERIOD*	DETERMINED SULFATE SULFUR			SULPHATES COMPUTED TO $CaCO_3$		
	North end†	South end‡	Mean	North end†	South end‡	Mean
1932	25	21	23.0	78	66	72
1933	22	18	20.0	69	56	63
1934	17	14	15.5	53	44	49
1935	22	19	20.5	69	59	64
4-year total....	86	72	79.0	269	225	248
Mean.....	22	18	20.0	67	56	62

* July to July.
† Quartz blank nearer to road.
‡ Quartz blank farther from road.

ADAPTATION OF FINDINGS

The results indicate the importance of a fine state of division and of judicious incorporations of limestone or of dolomite to assure adequate supplies of nutrient calcium and magnesium for soils of high quartz content. This holds especially for the less soluble dolomitic limestone. A conclusion seems warranted by a comparison of the composition of the leachates from the limestone-quartz and dolomite-quartz mixtures with the composition found for leachates obtained during the first 4 years after incorporations of limestone and of dolomite in a black Onslow fine sandy loam. The unfixed fractions of finely divided high-calcic limestone will give to the free soil-water a calcium concentration greater than that resultant from comparable quantities of calcium held in the soil complex, and a consequential decrease in the amounts of magnesium derived from the native magnesic components of the soil. Undecomposed incorporations of dolomite are less soluble than the fixation complexes that follow disintegration of the dolomite. After the dolomite undergoes disintegra-

tion in the soil, the amounts of magnesium dissolved from the magnesic complexes by the free soil-water may exceed the amounts of calcium dissolved from the calcic complexes. The quantities of magnesium derived from rain-waters, from soil, and from dolomite additions, and the aggregate supplies of calcium from the same sources are in such relationship that a toxic excess of magnesium will not occur. The desirability of maintaining an adequate supply of organic matter not only to develop a CO_2-impregnated soil-water to dissolve the incorporated limestones but also to produce organic complexes capable of fixing the calcium and magnesium supplied by the added limestones is also indicated.

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AN EFFICIENT AND CONVENIENT TYPE OF COOLING AND FREEZING BATH

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The dilatometer method has proved to be an excellent means of determining the permanent wilting point of soils (2) and the moisture equivalent of soils (3). Investigations now under way reveal that it can be used also to determine the normal field moisture capacity of soils. In all of these determinations, the dilatometer with its contents must be cooled and maintained at a temperature of exactly $-1.0°C$. The type of cooling bath that has been employed heretofore in these investigations, as well as in previous freezing point determinations, consisted of a small earthenware jar placed inside a larger one, the space between them being filled with asbestos fiber and sealed with melted paraffin (1). This type of cooling bath has never worked entirely satisfactorily, principally because the paraffin would either crack or draw away from the jar through contraction and thus allow water to enter the air space. When the air space became wet, the bath would not keep a constant temperature for any length of time. Furthermore, the earthenware jar, even though glazed, would absorb sufficient salt after long use to interfere in maintaining an exact temperature when the bath was freshly started.

Since the accuracy of the dilatometer method depends very largely upon maintaining an exact and constant temperature in the cooling bath, the necessity for a more efficient cooling bath is obvious. This necessity has led to the development of a new type of cooling bath (fig. 1) which has proved to be most efficient. It is made by placing a 12-quart galvanized steel pail inside a galvanized steel bushel basket, filling the space between them with rock wool, and sealing the top by brazing a strip of galvanized steel on the rims of the pail and the basket, thus making the insulating space permanently watertight and airtight. On the inside bottom of the pail is placed a piece of rubber-felt in order to provide a cushion for the dilatometer and thus minimize the danger of breakage. The inside of the pail is painted to prevent rusting. For a cover, a piece of rubber-felt is used, the felt side being waterproofed by paint.

The principal distinctive features of this new cooling bath may be summarized as follows:

It is permanent and nonbreakable, since it is made of metal.

Its insulating space is made permanently watertight and airtight, since it is sealed by brazing the joints.

It is extremely efficient; it will keep ice 3 or 4 days and a constant temperature with only occasional stirring.

It is light in weight, and the handles on the sides of the basket make it very convenient to handle and carry.

It is inexpensive and easily made.

This type of cooling bath may be used not only in connection with the dilatometer method but also in freezing point determinations generally.

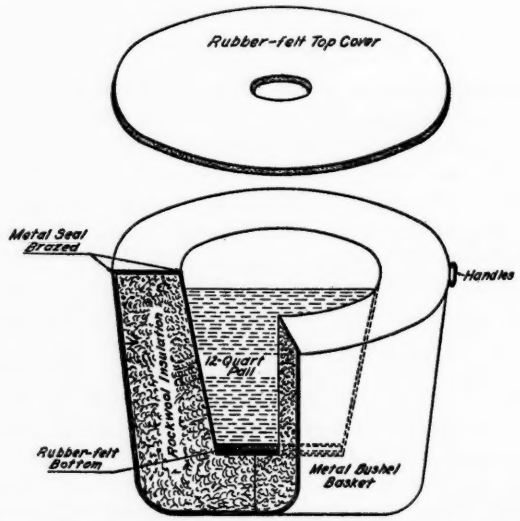

FIG. 1. AN EFFICIENT COOLING BATH USED IN CONNECTION WITH THE DILATOMETER METHOD AND IN FREEZING-POINT DETERMINATIONS

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THE LATERITES OF WESTERN SAMOA

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The object of this paper is to discuss the soil process involved in the formation of immature laterite in the tropics and the practical problem of the recognition of the stage to which the lateritic process has proceeded—in other words to select characters of the soil that can be utilized for the mapping of series.

Western Samoa—including Upolu and Savaii—lying almost wholly between latitudes 13 and 14°S., has an equable, humid, tropical climate. The mean temperature at the coast in January is 79°F., and that in July, 77°F.; progressively lower temperatures are, of course, experienced inland. The rainfall is 111 inches at Apia on the coast of Upolu; 200 inches at Tiavi (2,450 feet), the highest point at which observations were made in Upolu; and 170 inches 4 miles inland from Tuasivi on Savaii.

Basalt is almost everywhere the parent material of the soil; on the coast there is, in most places, a low-lying border a few chains wide in which an admixture of coral sand occurs. Observations were confined to the soils derived from the lava flows on the gentle slopes on the north of Upolu and on the east of Savaii. The flows are not all weathered to the same extent; where differences occur in the same climatic area, the flows are obviously not of the same age. In most localities the subsoil extends from 5 to 6 feet below the surface. Probably the basalts range in age from Pleistocene to Recent. Analysis (table 1) shows the composition of the fresh rock, which agrees fairly closely with that of ordinary basalts, except that titania is well above the usual amount.

Rain forest is the natural vegetation, and where this is cleared a thick mat of weeds soon develops unless weeding is practised. On the forest floor is a shallow leaf litter, less than an inch thick. The commercial crops grown in the areas examined are coconuts, cocoa, and bananas. Virtually no manuring has been done to date.

DESCRIPTION OF SOILS

The following soil types have been recognized: Saleimoa stony sandy loam, Vaitele stony clay loam, Magia stony clay loam, Tuasivi clay loam, Malatula

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stony clay loam, and Tiavi clay loam. These are arranged according to the degree of leaching which they are thought to have undergone, the least leached being Saleimoa stony sandy loam. All the types except Tiavi clay loam and Tuasivi clay loam may be considered as experiencing, roughly, the same climate. The rainfall on the soil types is Saleimoa 105–130 inches, Vaitele 110 inches, Magia 96 inches, Tuasivi 170 inches, Malatula 130 inches, and Tiavi 200 inches.

Saleimoa stony sandy loam

The profile of Saleimoa stony sandy loam is as follows:

6–9 inches	dark yellow-black-brown stony loam with good crumb structure
on	dark red-brown-yellow loose very stony sandy loam.

This is the most stony soil on Upolu: here and there are heaps of jagged stones. The lava flow from which it is derived appears to belong to the Recent age. The soil is neutral in reaction. The plant-nutrient status is good, the total nitrogen content of the topsoil being abnormally high (2.01 per cent).[3] As judged by the growth of cocoa and coconut threes, this soil is the most fertile of the six soils studied.

Vaitele stony clay loam

The profile of Vaitele stony clay loam may be described as follows:

6 inches	dark brownish yellow stony clay loam with good crumb structure
++ feet	brownish yellow moderately compact stony clay loam.

In several localities, a dark yellowish-brown compact layer about 1 foot or more thick lies 2 feet below the surface; in others, loose brownish-yellow clay loam extends for 3 feet below the topsoil; in yet others, the soil is dark red-brown-yellow to about 12 inches below the surface. In a detailed survey, the soil containing red coloring would be mapped as a separate type. Decomposed basalt containing cores of fresh rock lies, in general, from 5 to 7 feet below the surface. Although the texture of Vaitele stony clay loam is that of clay loam, the soil and the subsoil to a depth of 2 or more feet are, like most basalt soils, very loose. The pH ranges from 6.2 to 7.0 in the topsoil and subsoil layers. The available phosphate content is, in general, decidedly low, but the nitrogen content is adequate—0.48 to 0.68 per cent. This soil is generally less fertile than the Saleimoa soil; the most fertile areas are those containing red coloring.

Magia stony clay loam

The profile of Magia stony clay loam is as follows:

6 inches	dark brownish drab stony clay loam with crumb structure
12 inches	dark brownish drab loose clay loam
to 3 + feet	dark brownish drab fairly compact clay loam.

[3] Determinations of pH, available phosphate and potash, and total nitrogen were made at the Cawthron Institute, Nelson.

This soil is similar in content of available phosphate and in pH value to Vaitele stony clay loam but is less fertile.

Tuasivi clay loam

Tuasivi clay loam has the following profile:

3 inches	dark brownish yellow clay loam, poor crumb structure
on	light brownish yellow moist compact clay loam.

In places, a compact dark brownish-yellow horizon lies at a depth of 18 inches. The subsoil is inclined to be sticky. The soil is acid (pH 5.4), available phosphate is decidedly low, and total nitrogen (0.83 per cent) is higher than that in the Vaitele soil. Available potash appears to be adequate in the Tuasivi, Magia, and Vaitele soils.

Malatula stony clay loam

The profile of Malatula stony clay loam is as follows:

6 inches	dark brownish yellow clay loam, with crumb structure
10 inches	dark brownish yellow loose clay loam
32 inches	dark brownish yellow compact clay loam
on 1 foot	mottled black and yellow clay loam.

The compact layer is fairly general and is closer to the surface than is that in the Vaitele soils. Scattered profiles typical of the Vaitele soil occur within the areas mapped as Malatula stony clay loam. The pH of the Malatula topsoil is 5.6, and that of the subsoil ranges from 6.5 and 6.9. The content of available phosphate is decidedly low, that of potash is low, and that of nitrogen[4] is about equal to that of Vaitele stony clay loam. Malatula stony clay loam is the least fertile of the six soils studied, but coconuts growing on this soil have an economic life not much shorter than the average for such trees on a good soil.

Tiavi clay loam

Tiavi soils occur to the south of Apia on a saddle (2,254 feet) of the main range extending the length of Upolu. The profile of Tiavi clay loam is as follows:

3 inches	dark black-brown yellow sticky clay loam
19 inches	dark brownish orange sticky clay loam
6 inches	dark brownish yellow compact clay loam
on	reddish brown compact clay loam.

The subsoil is lighter in color than that of any of the other soils already described. The topsoil is not darkened by humus and is difficult to distinguish from the subsoil. The pH of the topsoil is 4.9, and that of the 6-inch dark

[4] The carbon-nitrogen ratios for the Saleimoa, Vaitele, and Malatula soils range from 11.85 to 14.24.

TABLE 1

Fusion analyses

Per cent

	BASALT ROCK FROM VAILELE, WESTERN SAMOA	SALEIMOA		MAUGA, VAITELE					CROWN ESTATE, TUASIVI, SAVAII			MALATULA				TIAVI SADDLE	
		0–3″	9–12″	0–3″	9–12″	21–24″	33–36″	57–60″	0–3″	12–15″	24–27″	0–3″	33–36″	45–48″	57–60″	0–3″	23–28″
SiO	38.41	23.64	27.36	15.65	15.35	14.37	11.87	12.57	6.73	4.95	4.35	3.73	1.08	1.13	1.21	2.50	5.82
Al_2O_3	15.15	23.28	23.20	33.73	33.97	34.15	35.10	35.54	35.02	36.10	37.47	35.76	37.88	37.74	37.41	34.98	30.83
Fe_2O_3, FeO	17.28	24.66	24.59	37.80	38.34	39.16	40.05	39.37	42.04	43.51	43.27	43.67	45.12	45.18	44.91	48.83	49.89
TiO_2	5.63	7.34	7.05	9.12	9.18	9.49	9.80	9.67	10.65	10.98	10.64	13.36	13.29	13.26	13.69	11.53	11.84
P_2O_5	0.82	0.52	0.29	0.98	0.88	0.92	0.99	1.00	1.09	0.75	0.65	1.13	1.06	1.10	1.09	0.70	0.51
Cr_2O_3	.....	0.14	0.15	0.21	0.26	0.23	0.25	0.26	0.37	0.34	0.33	0.18	0.13	0.18	0.19	0.49	0.25
CaO	9.77	9.22	5.72	0.58	0.49	0.43	0.50	0.39	0.76	0.38	0.29	0.18	0.03	0.06	0.03	trace	trace
MgO	10.98	10.40	11.12	1.03	0.84	0.81	0.57	0.74	2.59	2.50	2.52	1.24	1.03	1.05	1.26	0.62	0.85
Na_2O	0.48	0.25	0.25	0.11	0.11	0.05	0.05	0.04	0.09	0.07	0.05	0.07	0.06	0.06	0.06	0.06	0.03
K_2O	1.08	0.14	0.09	0.06	0.05	0.02	0.02	0.04	0.13	0.07	0.07	0.09	0.03	0.03	0.02	0.06	trace
MnO	0.25	0.45	0.38	0.79	0.76	0.64	0.67	0.53	0.74	0.54	0.48	0.65	0.51	0.37	0.50	0.14	0.22
Total	99.85	100.04	100.20	100.06	100.23	100.27	99.87	100.15	100.21	100.19	100.12	100.06	100.22	100.16	100.37	99.91	100.24

brown layer is 5.8. Available phosphate is particularly low, potash is low, and the nitrogen content is about equal to that of the Vaitele soil.

SOIL PROCESSES

The fusion analyses given in table 1 show that the soils are losing silica, principally, and alkalies and alkaline earths, as well. The youngest soil—Saleimoa—still retains most of its lime and magnesia, but has lost a good deal of silica. With progress of leaching, more silica is lost, until only 2.5 per cent is left in the Tiavi topsoil and 1.08 per cent in the Malatula subsoil. In the most mature soils very small amounts of the alkalies and alkaline earths remain. Manganese and phosphoric acid are apparently leached out to only a very minor extent or not at all. The principal fixed constituents are alumina, iron oxide, and titania. The analyses of Vaitele and Malatula soils show that there is surprisingly little difference in composition of soil and subsoil to a depth of 5 feet, which is, in many places, the depth to decomposed rock. The only difference noted in some profiles is a higher silica content in the topsoil than in the subsoil. The silica and other soluble constituents evidently do not form a B horizon at a shallower depth than 5 feet. In the field it was thought that the compact dark subsoil horizon at about 2 feet was a B horizon, but analyses do not support this view. Further work is required to determine the reason for this compact layer.

In the extreme stages of leaching the soils are just as low in silica as are the laterites of India (2). They compare in composition with the Nipe Plateau laterite of Cuba described by Marbut (3) except that in Samoa the content of alumina is nearly equal to that of iron oxide. Also the Cuban topsoil to a depth of 1 foot contains small round iron oxide concretions.

The clay fractions of the Saleimoa and Vaitele soils, shown in table 2, have similar silica-sesquioxide ratios—between 0.42 and 0.63. Further analyses, not included in the table, gave the following ratios: two of Saleimoa soil, 0–3 and 12–15 inches, ratios of 0.58 and 0.45; and four of Vaitele soil, 0–3, 9–12, 21–24, and 25–31 inches, ratios of 0.46, 0.46, 0.45, and 0.44. Thus the weathering of basalt in Western Samoa gives rise to a clay of a composition which, insofar as its silica and sesquioxides are concerned, persists for a fairly long time while silica and other constituents are being leached out. Soils having these ratios range in reaction from neutral (young soil) to only slightly acid (in the Vaitele series). The soils that are thought to be more leached have lower ratios. In the Malatula soil the ratio drops to 0.04. At Tuasivi the ratios are 0.14 and 0.19. The topsoil at Tiavi is very acid—pH 4.9, but the subsoil—pH 5.8—is of the same acidity as that at Malatula, and the ratios are 0.12 and 0.29.

Column 1 in table 3 shows the amount of free iron oxide in the soils of four series determined by Drosdoff and Truog's method (1). It is seen that the percentage of iron in the clay fraction of two—the Vaitele and the Tuasivi—is somewhat similar, but there is a fairly large difference in the sesquioxide ratios.

TABLE 2

*Clay fractions**

	SALEIMOA		MAUGA, VAITELE					CROWN ESTATE, TUASIVI, SAVAII			MALATULA				TIAVI SADDLE	
	0–3″	0–12″	0–3″	9–12″	21–24″	33–36″	57–60″	0–3″	12–15″	24–27″	0–3″	33–36″	45–48″	57–60″	0–3″	23–38″
SiO_2 ..... *per cent*	15.48	19.52	18.96	18.58	17.44	16.17	15.27	7.10	5.76	6.65	6.69	1.67	1.90	1.73	4.28	10.12
Al_2O_3 ..... *per cent*	38.09	30.51	35.24	35.79	36.04	36.24	36.42	37.20	43.51	33.23	35.46	34.77	30.61	30.24	24.98	25.43
Fe_2O_3 ..... *per cent*	28.35	34.87	37.98	38.13	38.80	39.80	40.47	42.54	40.24	47.33	47.22	51.82	54.80	54.58	56.62	52.34
TiO_2 ..... *per cent*	6.11	6.31	5.88	6.08	6.41	6.51	6.65	8.89	8.37	10.98	8.47	10.86	11.88	12.40	12.52	11.51
CaO ..... *per cent*	8.27	4.11	0.63	0.19	0.15	0.11	0.26	0.99	0.51	0.35	0.70	trace	0.06	0.04	0.63	trace
MgO ..... *per cent*	1.61	3.61	0.40	0.25	0.24	0.24	0.26	1.20	0.78	0.73	0.40	0.22	0.25	0.31	0.25	0.24
Na_2O ..... *per cent*	0.65	0.30	0.18	0.17	0.18	0.13	0.09	0.90	0.19	0.14	0.33	0.02	0.08	0.12	0.43	0.18
K_2O ..... *per cent*	1.03	0.35	0.14	0.09	0.04	0.04	0.04	0.59	0.11	0.08	0.11	trace	0.02	trace	0.20	0.09
MnO ..... *per cent*	0.41	0.42	0.59	0.72	0.70	0.76	0.54	0.59	0.53	0.51	0.62	0.64	0.40	0.58	0.09	0.09
SiO_2/R_2O_3	0.47	0.63	0.54	0.52	0.49	0.45	0.42	0.19	0.14	0.18	0.17	0.04	0.05	0.05	0.12	0.29

* The clay fractions were obtained by repeated sedimentation in water. The suspension was allowed to settle through a depth of 8.6 cm. for 24 hours, and the clay suspension was decanted and evaporated in porcelain on a water bath, the process being repeated until no further clay fraction could be obtained. To facilitate flocculation one or two drops of very dilute ammonia were added when absolutely necessary. In some samples 3 or 4 months were required to obtain the whole of the clay fraction.

It may be mentioned that soil erosion is not a complicating factor in the soil process. Under natural conditions there is a heavy forest cover with a thin mat of leaves. Water reaching the ground readily percolates downward. Even in the cocoa plantations where weeding is practised no erosion was noticed except on a moderate slope which was bare of fallen leaves. This is mentioned because Robinson (5) has stated that "The suggestion may be hazarded" that truncation of soil profiles during the course of time accounts for "the formation of the sesquioxidic soils of humid tropical regions."

USE OF THE TERM "LATERITE"

The process of leaching whereby silica is the main constituent lost is referred to as "laterization." The final stage in this process is the laterite of India, a typical section and description of which are given by Fox (2). On the surface is red or yellow clay lying on laterite consisting of bands or lenses of limonite and bauxite. The laterite lies on lithomarge (21–62 feet below the surface)

TABLE 3

Free iron oxide, total iron oxide, and silica in clay fractions

Per cent

	FREE IRON OXIDE	TOTAL IRON OXIDE	SILICA
New settlement near rubber factory, Saleimoa series, 0–3″	22.9	28.49	17.95
Solaua, Vaitele series, 0–6″	23.8	34.64	20.29
Vaitele, 0–3″	20.7	35.30	21.01
Fagalie, Vaitele series, 0–3″	26.5	38.96	15.68
Crown Estate, Tuasivi, Savaii, 0–3″	31.2	42.54	7.10
Tiavi Saddle, 0–3″	29.1	56.62	4.28

and kaolin which grade down to decomposed basalt. The lithomarge is a layer enriched by silica leached from the overlying soil and subsoil. A condition that is supposed to have favored the separation of iron oxide and alumina in the profile was a high ground-water level caused by the impervious lithomarge bed. A similar history for laterites in the tropics is given by Mohr, a summary of which has been published by Pendleton (4). Pendleton states that the final stage is truncation of the profile, exposing the hard ferruginous laterite, although, according to Marbut (3), in rare cases the slaggy material actually forms at the surface. Pendleton objects to the use of the term "laterite" for soils in which the process has not proceeded so far, for example, the red loam of southern United States. If truncation is not necessary or is an unimportant feature of the process we can regard the laterite as including all the profile except the B horizon in which the silica is deposited. That the term does not include the B horizon appears to be the only valid objection to its employment as a soil group name, but this does not seem sufficiently strong

to drop the term for soils like those of Samoa, when it is remembered that such usage is widespread.

CLASSIFICATION INTO SERIES

To divide laterites derived from basalt into soil series presents a good deal of difficulty. The following field characteristics were used in classifying:

Amount of weathering undergone by the basalt. Saleimoa soils are easily separated on this basis, and Vaitele and Malatula soils can be distinguished in this manner.

Color of soil. In similar climates the young soils show a red coloring to a depth of about 12 inches—Saleimoa and the less well-developed soils of the Vaitele series. In the areas of very heavy rainfall, the subsoil immediately below the topsoil had lost its brown coloring and taken on an orange color.

Compact layer in the subsoil. The presence of a compact layer which when moist was of darker color than the overlying subsoil was taken as evidence of greater leaching than that of a similarly colored soil in which such a layer was absent.

Compactness of subsoil. In areas of very high rainfall the subsoil is compact and sticky.

These characteristics are hardly an adequate basis for mapping out series with any confidence, as they are not constant; for example, in areas where the compact layer is present in general, there are many places where it is absent.

Recourse must be had to chemical analyses, of which the most reliable and quickest seems to be the determination of total silica. Clay fractions are of only limited use, since the silica-sesquioxide ratio in obviously young soils is the same as that in some of the older soils. A number of silica analyses were made, including some from private plantations, and it was found that the fertility as determined by crop yields was in direct proportion to the silica percentage. The analyses fitted in with the series already established and helped to place some doubtful localities. Total silica determinations will, it is concluded, be useful in determining limits for the various series.

SUMMARY

In Samoa the lateritic process has gone far without segregation of iron oxide and alumina.

The lateritic process is going on in a young soil which still retains most of its lime and magnesia.

Most of the soils losing silica are only slightly acid or are neutral. A very acid soil, as well, is losing silica.

In the most extreme stage the soils are just as low in silica as are many of the laterites of India.

Although some soils contain virtually only alumina, iron oxide, and titania, they are still capable of producing profitable crops for many years without fertilizers.

All the soils have a surprisingly high content of total nitrogen.

The younger soils contain red coloring, and older soils, although well drained, take on a dark brownish-yellow color.

Silica-sesquioxide ratios of the clay fractions remain constant for a fairly long period in the process—as far as the Vaitele stage. In the well-leached soils the ratio drops extremely low.

To a depth of 5 feet in the profile no marked difference occurs in total constituents or in the composition of the clay fractions.

Laterite soils derived from basalt are difficult to classify on the basis of field characteristics. All the usual chemical analyses can be utilized to assist, but obviously the amount of this work is limited on the score of expense. The determination of total silica is thought to offer the most reliable and quickest aid.

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FERROMANGANIFEROUS CONCRETIONS FROM SOME PODZOLIC SOILS

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Concretionary matter in soils represents accumulations of secondary minerals that have been formed through the action of weathering processes. A survey of the literature indicates that concretions occur in all the soil zones from the podzol to the laterite and from the chernozem to the serozem. Ortstein and the associated "ortsteinkoerner" of the podzols have been described by Glinka (5); lime concretions are a recognized characteristic of the pedocal group of Marbut (7); Bennett and Allison (2) direct attention to the abundance of ferruginous concretions in lateritic soils.

Concretions in the extensive group of podzolic soils have been mentioned less frequently. Podzolic soils are considered to occupy that wide transition zone in humid climates between true podzols and lateritic soils. A few references that include analyses of concretions from podzolic soils indicate that Mn as well as Fe is an important constituent. Thresh (11) has noted the presence of "Mn nodules" in England; Tsukunaga (12) studied two varieties of concretions in Manchuria, the "red" being low in Mn, and the "black," high in Mn; Pelisek (8) recognized seven types of concretions in the glei soils of Moravia that contained from 1 to 15 per cent Mn_3O_4; Zvorykin (13) working in Greece, reported 5.5 per cent Mn_3O_4 in the concretions from a red soil, which is here considered to fall in the podzolic group, though the possibility of lateritic influences in that vicinity is recognized. The term "ferromanganiferous" is used, therefore, to characterize the podzolic type of concretion. This does not imply that Mn is absent from other types of concretions, but rather that it is less consistently present in significant proportions.

The presence of ferromanganiferous concretions has previously been noted in some soil types in Illinois (6). That conditions favorable to the development of podzolic soils obtain in Illinois is indicated by the climate. The average annual temperature varies from 47°F. in the north to 58° in the southern part of the state, and the rainfall varies concurrently from 32 to 45 inches. Little climatic variation is observed from east to west. The native vegetation under virgin conditions included both long grass and deciduous forest, the former giving rise to dark soils, and the latter, to light-colored soils. More detailed information about the soils of Illinois is given by Smith et al. (10).

This paper treats of the ferromanganiferous concretions occurring in Illinois

from the following three points of view: physical properties; distribution by soil type and by horizon; and composition and its relation to the composition of the total soil mass.

PROCEDURE

Observations on the distribution of ferromanganiferous concretions in Illinois soils have been made during the field study of soil profiles. The information so obtained was, of necessity, qualitative in nature and served chiefly to indicate the conditions under which concretions were abundant. Later, more detailed studies were made of the sand fractions obtained during mechanical analysis. The concretions so obtained were separated from the siliceous material with a magnet, and the percentages by weight were determined.

The comparison of soil and concretion composition was made on concretion specimens collected by H. J. Snider from several of the Illinois Soil Experiment Fields from which soil samples were also available. Specimens for further study were collected from definite soil types, horizons of which contained large concretions in sufficient quantity to make collection by hand feasible. Locations were chosen in widely scattered areas throughout Illinois. The specimens of concretions in surface horizons were picked up from the surface of cultivated fields. Specimens from the lower horizons were picked out of the vertical profile exposed when a hole was dug. The concretions collected ranged in size from about 6 to 1 mm., those smaller than 1 mm. being disregarded. Duplicate samples were taken from areas of the same soil type, usually several miles apart.

The relation of size to composition was studied on a sample screened from a considerable weight of soil. These specimens were separated into three size groups, and the analysis of each was made separately.

All the concretions analyzed were washed free of adhering soil particles before being ground. Standard methods of analysis were used in all cases.

PHYSICAL PROPERTIES

The typical ferromanganiferous concretions found in the solum of the podzolic soils in Illinois are reddish-brown to nearly black and vary in diameter from less than 0.050 mm. to more than 10 mm. Their form is usually spherical, though the surface is often roughened or irregular. Most specimens show concentric fracture when broken, thus giving evidence of a layered structure. Hardness is variable, but those specimens with the best developed fracture are usually the hardest. Inclusions of sand grains and other soil material within the concretions are numerous and give the impression that the cementing material has been deposited in the soil pore spaces. Zvorykin (13) has described concretions from Greece that have some similar properties.

Almost all the concretions examined show a slight magnetic susceptibility, though a very strong field is required to demonstrate it. Ignition greatly increases this magnetic susceptibility, as has been mentioned by Bray (3) except

in those specimens from the deeper horizons where organic matter is almost absent. The addition of a reducing agent, as sugar, will cause these concretions to become magnetic also, probably by reducing some of the Fe_2O_3 to Fe_3O_4. Magnetization by ignition provides a convenient method for the separation of concretions from siliceous material.

When ground for analysis, the concretions yield a powder that varies from very dark brown for those high in Mn, to buff or yellow for those low in Mn.

Not all ferromanganiferous accumulations in the soil are coherent and hard enough to maintain their form when handled. The brownish splotches and the soft, easily pulverized bodies, both of which are of rather general occurrence, are of this incoherent type.

OCCURRENCE

Ferromanganiferous accumulations seem to be present in the solum of most soil types occurring in Illinois, either as concretions, or in the form of diffuse reddish splotches. There are great differences, however, in the relative abundance and size of concretions, not only between different types, but also between the several horizons of the same profile. Field observations over a period of years have indicated that certain environmental and soil features are associated with the presence of large concretions in appreciable numbers. The most important of these features are the following:

Poor drainage.—In surface horizons this is usually associated with level topography.

Light-colored soils.—In general, soils that have been subjected to considerable degradation.

Solonetz-like soils.—Slick spot conditions described by Smith (9). This situation is unusual in that calcareous, as well as FeMn concretions are abundant, whereas the solum of most Illinois soils is leached of $CaCO_3$.

These observations are interpreted to mean that most pronounced concretion formation is correlated with intensive or prolonged weathering, with the slow removal of the end-products of weathering from the profile, and with the frequent alternation of reducing and oxidizing conditions in the soil. Similar conditions are implied by Zvorykin (13) and by Pelisek (8) when they point out that concretions are found in soils frequently subjected to a high water table.

Certain "pipestems" in loess and the irregular masses which appear to be formed by ground-water action represent ferromanganiferous segregations that are frequently encountered. Since these concretionary forms probably are not directly concerned with soil processes, they will not be discussed here.

In the course of mechanical analysis the sand fraction is separated by an approximately 0.05-mm. screen. Concretions of this size and larger are thus retained with the other coarse material, from which they may be separated with a magnet after gentle ignition, as has been described. In this way it is possible to determine the percentage of concretions larger than 0.050 mm. in a given sample of soil.

The sand fractions of many hundreds of samples have been examined for concretions, which were found to be present almost without exception, though the relative abundance varied tremendously. The samples represented a wide range in soil characteristics, including virtually all conditions prevalent in Illinois with the exception of the group of coarse sandy soils of restricted distribution. It is possible that very sandy profiles might not contain concretions, since their good drainage would facilitate the removal of what little secondary material was formed.

A surprisingly large number of the concretions found with the sands were very small. Some of these may be fragments of larger concretions that had been broken during the preparation of the soil for mechanical analysis, but many of the small specimens examined showed no fracture, and, on the contrary, possessed rather smooth, rounded surfaces, indicating that they were genetic units.

The extreme scarcity of large specimens in most soils explains why ferromanganiferous concretions are overlooked in many field descriptions of soil

TABLE 1

The concretion content of some surface soils

SOIL		CONCRETIONS
		per cent
West Salem Experiment Field	Plot 105	5.5
	106	5.6
	107	5.9
	108	6.2
Sparta Experiment Field Plot 205A		5.5

profiles. The concretions in well-drained soils generally do not exceed 1 mm. in diameter and thus are not easy to discover; consequently, they were formerly thought to be absent in such soils in Illinois. Similarly in most dark-colored prairie soils, field observations usually fail to detect the concretions present.

Table 1 gives the percentage of concretions found in the surface of some highly weathered, level soils containing heavy claypans that impede drainage. Locally, farmers call these soils "buckshot" land because of the abundance of large concretions found on plowed fields. The variation in the concretion contents of these soils from West Salem and Sparta is less than might be expected. Though 5 to 6 per cent of concretions is not high compared to contents up to 38 per cent reported by Bennett and Allison (2, p. 360) for lateritic soils, yet it represents a considerable segregation of ferromanganiferous material for podzolic conditions. Tsukunaga (12) found only 2.8 per cent of concretions in the Manchurian soil he studied.

The concretion percentages by horizons are given in table 2 for two complete profiles, both highly weathered forest soils, one of which (Ava) is well drained,

and the other (Wynoose), poorly drained. Both show, in general, a decrease of concretions with depth. A parallel observation was made by Tsukunaga (12) for a Manchurian soil, which had 2.8 per cent in the upper 50 cm. and only 0.4 per cent at a depth of 150 to 200 cm. The upper horizons of most soils should probably contain more, as well as larger, concretions, since this part of the profile has undergone greatest weathering. The Wynoose, however, has slightly more concretions from 30 to 43 inches than in the horizons either immediately above or below, which substantiates a field observation that concretions seem to be more abundant in definite layers or zones in some profiles.

The higher percentage of concretions in the poorly-drained Wynoose when compared to similar horizons of the well-drained Ava is in agreement with the

TABLE 2

The distribution of concretions in two profiles

AVA SILT LOAM			WYNOOSE SILT LOAM		
Laboratory Number	Depth	Concretions	Laboratory Number	Depth	Concretions
	inches	*per cent*		*inches*	*per cent*
15091	0–6	1.9	15051	0–4	3.4
15092	6–10	1.2	15052	4–9	2.6
15093	10–14	1.0	15053	9–13	2.9
15094	14–17	0.7	15054	13–18	2.5
15095	17–20	0.6	15055	18–21	1.4
15096	20–23	0.8	15056	21–24	1.2
15097	23–25	0.6	15057	24–27	1.0
15098	25–28	0.7	15058	27–30	1.0
15099	28–31	0.5	15059	30–34	1.5
15100	31–34	0.5	15060	34–39	1.5
15101	34–38	0.5	15061	39–43	1.6
15102	38–42	0.7	15062	43–50	1.0
15103	45–50	1.0	.....	.....	...

general observation that poor drainage is associated with a greater abundance of concretions.

CHEMICAL COMPOSITION

Further justification for the term "ferromanganiferous" suggested above will be apparent from the following data on composition. In table 3 are presented fusion analyses of some concretions and of the soils from which the concretions were collected. In general, the concretions are much higher in Mn_3O_4 and Fe_2O_3, a little higher in Al_2O_3, and lower in both SiO_2 and carbon than the soils in which they were found. The segregation of manganese, in particular, is noteworthy, more than 50 times as much being in these concretions as in the corresponding soil.

The summation column of Table 3 indicates that 2 to 4 per cent of the

constituents are unaccounted for. Of the unreported constituents, P_2O_5 and TiO_2 precipitate with the Al_2O_3 and so are included in the totals with this fraction. Qualitative tests indicated that CaO, MgO, K_2O, and Na_2O are present in about the same proportions as in soil. As was mentioned under "Physical Properties," soil material is imbedded throughout the concretions, and therefore the usual minor constituents of soils will also be present in the

TABLE 3

Analyses of some soils and concretions therefrom

SAMPLE		IGNITION LOSS	SiO_2	Mn_3O_4	Fe_2O_3	Al_2O_3	SUMMATION	ORGANIC CARBON
		per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
West Salem Plot 105	Soil	4.8	79.6	0.14	3.0	8.7	96.2	0.91
" " " "	Concretions	11.0	50.7	11.3	14.0	11.3	98.3	0.38
West Salem Plot 109	Soil	4.7	81.6	0.12	2.8	7.9	97.1	1.06
" " " "	Concretions	10.1	50.1	6.6	21.1	9.4	97.3	0.42
Sparta Plot 205A	Soil	3.3	82.8	0.16	1.8	7.7	95.8	0.61
" " "	Concretions	9.6	50.4	11.5	15.8	10.6	97.9	0.27
Carlinville Plot 405	Soil	7.0	76.4	0.06	2.6	9.0	95.1	1.80
" " "	Concretions	10.3	46.6	3.6	24.3	10.7	95.5	0.56

TABLE 4

Analyses of concretions from certain soils

SOIL TYPE	HORIZON	LABORATORY NUMBER	IGNITION LOSS	SiO_2	Mn_3O_4	Fe_2O_3	Al_2O_3	SUMMATION	ORGANIC CARBON
			per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Wynoose silt loam	A_1	b428	9.8	54.6	13.2	9.0	11.2	97.8	0.33
" " "		b535	9.2	53.2	13.1	11.6	10.7	97.8	0.44
Rushville silt loam	A_1	A793	10.2	51.9	11.1	14.0	10.5	97.7	0.88
" " "		A237	12.0	39.0	8.8	27.2	11.0	98.0	....
Putnam silt loam	B_1	b344	9.6	50.2	6.7	18.1	11.9	96.5	0.27
" " "		b856	9.0	53.2	7.7	13.8	12.2	95.9	0.00
Grundy clay loam	B_2	b121	10.6	47.8	7.0	21.0	10.9	97.3	....
" " "		A391	10.5	49.2	9.2	17.9	10.9	97.7	0.54
Denny silt loam	B_2	A113	9.5	50.0	8.1	16.8	12.1	96.5	0.24
Illinoian gumbotil	B	A846	10.3	46.2	10.3	17.8	11.8	96.4	0.12
"Pipestem" from loess		13	10.5	43.8	3.2	30.4	7.9	95.8	0.59

concretions. A complete analysis of a soil similar to that at West Salem is given by Brown, Rice, and Byers (4, p. 31) and is indicative of the unreported constituents to be expected in the concretions.

Organic matter was found by Aarnio (1) to be important in some types of ortstein formation. The fact that the concretions contain less than half as much organic matter as do the soils (table 3) indicates that the organic matter is of minor importance, at least in these samples. The high ignition losses probably represent water associated with the Fe_2O_3 of the concretions, since

the organic matter content is less than 1 per cent (assuming the usual factor of 1.7 to convert carbon to organic matter).

Significant variations that are not related to the soil composition occur in the composition of the concretions reported in table 3. Further evidence on this point can be deduced from the analyses of a number of additional samples collected from soil types widely distributed throughout Illinois (table 4). They all show the marked concentration of Mn and Fe, the high ignition losses, and the low carbon content that characterized the concretions of table 3. The marked similarity of the composition of all samples suggests that local conditions are of less significance in the formation of these concretions than are general weathering processes common to the region. For example, there is more difference between the two samples from the Rushville surface than there is between samples from different horizons and from different soil types. Further, the sample from the gumbotil, which is a B horizon developed before the advent of the Wisconsin glaciation, has nearly the same composition as one from the Grundy B horizon, which developed on material of Wisconsin age.

TABLE 5

Relation of size of concretions to their composition

SOURCE OF SAMPLE	DIAMETER OF SPECIMENS	IGNITION LOSS	SiO_2	Mn_3O_4	Fe_2O_3	Al_2O_3	SUMMATION
	mm.	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Ewing Soil Experiment Field Plot 310	>2	10.3	46.3	8.3	22.4	10.4	97.7
	2 to 1	10.6	48.3	2.0	26.3	10.0	97.2
	1 to 0.3	11.0	50.3	1.4	24.4	10.7	97.8

"Pipestems" in loess appear to have been formed in old root channels, for they possess a concentric cylindrical structure that is difficult to explain in any other way. Their wide occurrence lends interest to their properties, and on this account one analysis is included in table 4. Though somewhat lower in Mn and Al than are the soil concretions, it exhibits in general a similar composition.

A definite relation seems to exist between size and composition of concretions in some instances. The data in table 5 illustrate this for one sample. The chief variable is the content of Mn, which shows a steady decrease with diminishing size, while Fe tends to increase, but less consistently. More data are needed to determine how general the correlation between size and Mn content may be.

SUMMARY

Field and laboratory studies have been made of the FeMn concretions occurring in the podzolic soils of Illinois. The results are presented under three headings, as follows:

Physical properties.—The concretions examined were irregularly spherical, dark brown, moderately hard bodies that varied in size from 10 mm. to less than 0.05 mm. They become magnetic after gentle ignition.

Occurrence.—In general, concretions were found to be most abundant in the surface horizons of poorly-drained, light-colored soils, though a few small ones were present in virtually all horizons of nearly every soil type.

Composition.—The concretions were found to be much higher in Mn and Fe, slightly higher in Al, and lower in SiO_2 and organic matter than were the soils in which they occurred. Large concretions were found to be higher in Mn than were small ones.

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THE PRESENCE OF TITANIA IN CHEMICALLY UNWEATHERED SOILS

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Joffe and Pugh (7), who have investigated the titania content of many different soils, are of the opinion that the chemical soil-forming processes are the cause of the differences noted. This may be true of the soils investigated, but surely under other climatic conditions soils exist in which the differences in the contents of titania are due to another, purely mechanical, process.

According to the oldest published investigations, the texture of the soil and the content of titania seem to be dependent upon each other. This is evident although the classification is not based directly upon the mechanical composition of the soils.

Dunnington (3) determined the titania content of 72 soils, of which 40 were from the United States, and the rest were from different parts of the world. The textural composition of 31 samples was designated. Of these samples, 19 were clays, 10 loams, and 2 sands. The average percentages of titania in these three different textural groups were as follows: clay, 1.38; loam, 0.77; sand, 0.20.

Dunnington is of the opinion that iron and titania are found simultaneously in soils because titania is contained in ilmenite, one of the commonest rock minerals. In soils having a low content of iron, he thinks, the titania occurs as titanite.

Robinson (9) investigated 26 soil samples from the United States and determined titania in all of them. According to the chemical analyses, the soils investigated are quite different from the soils of Finland, and the chemical theory of the enrichment of titania in these soils may, therefore, be true. The following tabulation shows, however, that the titania content of the fine-textured soils is higher than that of the coarse-textured soils:

SOIL	NUMBER OF SAMPLES	TITANIA CONTENT
		per cent
Clay	2	1.08
Clay loam	2	1.22
Silt loam	8	0.72
Loam	5	1.14
Sandy loam	6	0.71
Stony loam	2	0.75
Fine sand	1	0.60

Silt loam seems to be an exception to the general rule, but this may be explained by mechanical analyses, which show that the clay fraction in silt loam was the smallest determined.

Robinson thinks that the titania occurs as rutile or rutile inclusions in quartz. He has noticed, however, that the amount of quartz in fine fractions is smaller than that in coarse fractions, and it may be supposed that this is true also for soils of fine texture. The mineralogical investigations of sand and silt fractions show that the quantity of muscovite is higher in every sample of silt than in the two sand fractions separated. The relation between texture and titanium content is expressed very clearly by Geilmann (5), who after an investigation of 30 samples, came to the following conclusions:

> The clays are the richest in titania, the content of which reaches 1 per cent.
> The quantity of titania in loam and silt soils is smaller, followed by that in sand and calcareous soils.
> Pure chalk and sand contain very small quantities of titania.
> No sample has been found quite free from titania.

The same conclusions can be drawn from the aforementioned investigations, as well as from the investigations of Robinson et al. (10, 11) and of Joffe and Pugh (7). The last mentioned scientists have observed that soils rich in iron also contain titania in greater quantities than do soils of low iron content. They are of the same opinion as Dunnington that the titania is contained in ilmenite, thinking that ilmenite is formed anew, especially in the B horizon, during the process of podzolization. Another compound that would explain the presence of titania is Ti-Ti $(HPO_4)_2$. Joffe and Pugh ascribe the variations in the contents of titania to the weathering processes of soils. It is also quite natural that titania as well as iron can move from one place to another and be enriched through podzolization in the B horizon or through the laterization process.

The purpose of this investigation is not, however, to try to explain the vicissitudes of titania in the soil-forming processes. The discussion deals rather with the original titania content of soils as they are formed through the action of the sea in such countries as Finland, which has risen from the sea in the course of many thousands of years and of which the finer homogeneous soils at least are formed through the action of waves along the beaches of seas and lakes (13). As this process of soil formation involves the grinding of unweathered rock material and takes place very rapidly, the soils are formed in Finland and in the Scandinavian Peninsula in the same manner as are those in northern Russia where the common rock minerals form the soil, namely, from undecomposed rock material of different degrees of fineness. The original mineral composition of the rocks has naturally been changed during the wearing and sedimentation processes; some minerals have decreased and even disappeared, and others have increased according to such individual properties as specific gravity, hardness, and cleavage.

As the soil-forming processes in Finland are not very significant, the possibilities of following the primary characteristics of soils are very good.

For the present purpose, it must be remembered that all the aforementioned titania minerals are of such hardness and specific gravity that their enrichment in mechanical sediments is not easily explained. Although ilmenite is one of the commonest minerals in rocks, its enrichment cannot be explained on the grounds already set forth. Its specific gravity is between 4.5 and 5.0, and its hardness is the same as that of quartz. As quartz is one of those minerals the quantity of which is decreased in the course of the grinding and sedimentation processes, the increase of ilmenite during the same processes is improbable. The same holds true for other titania minerals, such as titanite and rutile. Although titanite is softer and lighter than the other titania minerals, its density, 3.5, exceeds the densities of common soil-forming minerals by one unit. Thus it seems improbable that the increase of titania in the above soils depends on the concentration of these titania minerals during the grinding and sedimentation processes.

All that has been said naturally holds true only when the mechanical sediments are considered. In other soils, other processes may prevail, and the increase and decrease of titania may depend upon them.

During the mechanical processes which have ground and sedimented the soils here in question, one of the main features of the change in mineral composition is the increase of micas in soils as the average diameter of the grains decreases—an observation first made by Atterberg (1). Mica is a little heavier than quartz and the feldspars, but its softness and its capacity to float in water, depending upon its cleavage into thin and comparatively broad tables, account for the increase of this mineral. I have shown in a previous publication, through calculations based on the chemical composition of Finnish clays, that the mica content of such clays must be very great (12). Furthermore, röntgenographic investigation has shown that the mica content of mechanical clays may be very high.

As the continual increase of micas in Finnish clays seems to be proved, it is of interest to try to explain the increase of titania on this basis. Micas and amphiboles are the two groups of titania minerals which may be encountered in clays. The increase of amphiboles is hampered, however, by their hardness and comparatively high density, 3.0–3.5. The feldspars and the quartz are free from titania. The content of titania in micas, on the contrary, is very high. The analyses of micas, published by Iddings (6), show a range in titania content from 1 to 5 per cent; in lepidomelanes the range is from 2.61 to 4.73 per cent. In many Finnish rocks the micas are of the last-mentioned type. The micas of clays are generally considered to be muscovites, the titania content of 13 samples of which was found by Doelter (2) to range from 0.11 to 3.94 per cent, averaging 1.30 per cent. The titania content of Finnish biotites, according to Lokka (8), averages 2.5 per cent, one biotite being free from titania.

These quantities of titania in micas readily explain the titania content of Finnish clays, which generally ranges from 0.5 to 0.8 per cent. The quantity of micas in clays calculated by me ranges from 20 to 50 per cent, and the quantity of titania increases simultaneously with the calculated increase of micas.

The average titania content of 27 Finnish clays was calculated to be 0.68 per cent. These clays include many different kinds, from coarse loamy clays to the very stiffest clays in which the fraction under 0.002 mm. amounts to 90 per cent. The average titania content of 12 sand samples was 0.40 per cent.

The best test for the increase of titania together with the micas is, however, the observation that when a mechanical analysis of a clay is made, the titania is found in greatest quantities in the finest fraction. An example is given in the following analysis of a Finnish clay (12), together with an analysis of the finest fraction (under 0.002 mm. diameter) of the same clay, calculated on the water-free and humus-free basis:

	ORIGINAL CLAY	0.002-MM. CLAY FRACTION
	per cent	*per cent*
SiO_2	65.24	59.22
TiO_2	0.77	1.14
Al_2O_3	15.79	20.23
Fe_2O_3	2.92	4.90
FeO	3.37	1.84
MnO	0.08	0.08
MgO	2.27	4.05
CaO	2.66	1.99
Na_2O	3.72	3.96
K_2O	3.01	2.49
P_2O_5	0.17	0.09
Total	100.00	99.99

The increase of titania in the fraction under 0.002 mm. as compared with the titania present in the original clay has been very great, and the explanation that the titania has been increased together with the micas is plausible. If titania were in the clay in the form of some weathering product, it would be concentrated in coarser fractions because of its high specific gravity.

One of the best examples of the increase of titania in clays is reported by Tamm (16). He ground very fine a granite, the mineralogical and chemical composition of which had been thoroughly investigated. The fine powder was treated for 12 hours both with water containing carbon dioxide and with common distilled water. The clay fraction of each of three samples was separated and analyzed, all three analyses being of about the same general character. Although the granite used contained only 0.89 per cent titania, the titania in the clay fraction averaged 2.40 per cent. The titanite content

of the granite was 0.34 per cent; therefore only 0.14 per cent of the total titania occurred in the titanite. The hornblende content of the granite was 7.64 per cent; therefore the hornblende contained 0.11 per cent of the total titania, for, according to Sundius (15) the titania content of the hornblende was 1.47 per cent. The titania content of micas must be, therefore 0.64 per cent; accordingly, the greatest part of the titania in the rock itself was in micas. As the quantity of titania in the clay fraction is about three times as high as that in the rock, it is evident that the increase of titania must be due primarily to the increase of micas during the sedimentation process in this experiment. Because of the very short duration of the experiment, changes of these dimensions cannot be ascribed to chemical reactions. The Al_2O_3:TiO_2 ratio of the clay and that of the calculated mica seem to bear out these conclusions, for the ratios are almost equal, the former being 6.25, and the latter, 6.43.

The artificial clay fraction of Tamm differs in many ways from the clay fraction separated from the aforementioned Finnish clay. This may be because the natural sedimentation process separated the different minerals much more thoroughly than did the comparatively short artificial separation. It must also be kept in mind that the granite used by Tamm contained no muscovite, which is considered to be the main constituent of the clay micas.

The foregoing experiments show that the increase of titania in these artificial clay fractions or separates can be explained only as a result of the increase of the micas. The titania content of clay minerals is very low, according to the analyses of Engelhardt (4). The quantities of titania in the different groups of clay minerals are as follows:

CLAY MINERAL	NUMBER OF SAMPLES	TITANIA CONTENT
		per cent
Kaolinite and anauxite	10	0.46
Dickite	1	trace
Halloysite and metahalloysite	..	....
Montmorillonite	5	0.50
Beidellite	1	0.84
Nontronite	4	0.04
Clay minerals rich in magnesia	1	0.44

The titania content of all these minerals seems to be so low that the high titania content of mechanical sediments cannot be explained by the presence of larger quantities of these minerals.

One other observation makes improbable the theory of the increase of titania through chemical weathering in clays of mechanical origin. The general occurrence of titania in chemical combination with iron leads one to suppose that if titania were in the form of weathering products in the clays in question the presence of iron would also be probable. The characteristic red-brown color of iron is not found, however, in Finnish clays under the generally thin

layer which lies above the ground water and in which only very slight weathering of the clay can be discerned. It is only after our clays have been heated to 400 or 500°C. that the first faint tinge of iron can be observed, and at these temperatures the decomposition of silicates begins, and iron can be found in the form of oxide. As it must, accordingly, be certain that iron is not originally present in the form of hydrates or oxides or in any other form of hydrolytic decomposition, it is impossible to believe that titania should be increased in this manner. Among the many kinds of clays are some that contain iron in the form of hydrolytic decomposition products, but the iron in these clays occurs in greater quantities (14) in the coarse fractions than in the fine fractions, a phenomenon not encountered in mechanical clays.

SUMMARY

Investigations, both old and new, have demonstrated that the titania content and the textural composition of soils are dependent upon each other, in that fine-grained soils contain more titania than do coarse-grained soils.

As the common titania minerals are hard and have a very high density, their enrichment, especially in mechanical sediments, is highly improbable.

In mechanical sediments the only minerals that can explain the variations of titania are the micas.

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ISOHYDRIC pH VALUE OF SOILS AND ITS DETERMINATION

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Problems connected with soil reaction and related phenomena constitute one of the most important branches of soil science. Methods of measuring the pH value of soils have received considerable attention, and some of these have attained a high degree of refinement and precision. The weak point in all these methods lies in the very nature of things. A soil suspension behaves like an ordinary buffer solution, but the analogy is not complete insofar as the one is a heterogeneous and the other a homogeneous system. In an ordinary buffer solution, the hydrogen and the hydroxyl ions are uniformly distributed throughout the liquid mass; whereas in a soil suspension, they are confined to the portion of liquid immediately in contact with the surface of the particles and can be easily filtered off. Under such conditions, it is doubtful whether we are justified in speaking about the pH value of soils without reference to the arbitrarily fixed conditions under which the actual measurements were carried out. On theoretical grounds, every soil should have a fixed pH value determined entirely by the amount and nature of exchangeable bases in it. The pH value of the soil should, therefore, be a fundamental constant not subject to rapid variations. Actually our methods of measurements give a value which fluctuates with alterations in the experimental conditions. Need was, therefore, felt for an absolute measure of the pH value of soils and other related phenomena. This paper deals with such a method.

The investigation was originally started from theoretical considerations, as it was thought that modern electrical methods of pH determination are sufficiently simple and quick that it would be difficult to replace them by a chemical method for ordinary routine work. The chemical method, however, entailed a procedure that afforded so much other information which is useful in any soil investigation, that the method could be recommended for inclusion in routine soil examination. In order to distinguish from other methods of determining soil reaction, the isohydric pH value of a soil may be defined as the pH value of a buffer solution which shows no change in reaction on coming into contact with the soil. Mattson[1] has called this pH the point of exchange neutrality.

[1] Mattson, Sante 1931 The laws of soil colloidal behavior: VI. Amphoteric behavior. *Soil Sci.* 32: 343.

EXPERIMENTAL

The starting point of this investigation was the following assumptions:

A fully unsaturated soil behaves like an acidoid with a well-defined titration curve.

The pH value of every soil in nature represents a single point on its titration curve governed by the state of its neutralization with bases. It is, therefore, a buffer mixture of a definite proportion of acidoid-saloid, which determines its pH value.

Soil if shaken with a buffer solution will have its acidoid-saloid equilibrium point shifted toward that of the buffer solution. In other words, it will take the basic portion from a buffer solution of higher pH value and give its basic portion to one with a lower pH value than that of itself. Consequently, when no change occurs in reaction, the soil and the buffer are isohydric, i.e., the pH value of the soil is equal to that of the buffer solution.

It is to be remembered that when a soil is shaken with water, it hydrolyzes, and a part of the exchangeable base goes into solution as hydroxide. Since the amount of the hydroxide going into solution depends on the state of saturation or pH value of the soil, and since the actual amount of the base removed from the soil and going into solution is very small, the pH value of the water approximates that of the soil. In natural soils, however, this ideal condition is seldom attained. There is always some salt present, which can suppress this hydrolysis, thus resulting in an increase in the H-ion activity or a lowering of the pH value. The ideal method, therefore, would be the one in which no hydrolysis is allowed to take place. In the isohydric method, this state of affairs is realized by interpolation, for, by definition, the isohydric pH value represents the pH value of that buffer solution which undergoes no change when coming into contact with the soil. This situation can exist only when the pH value of the soil is equal to that of the buffer solution; if the reaction of the buffer and that of the soil are different, some change must inevitably take place, resulting in the transfer of the base from one to the other. In short, the isohydric method depends not on a single measurement, but on a series of titrations from which the buffer in which the soil would undergo no change is determined; an absolute measure of the pH value of the soil is thus obtained. All other methods must involve some change in the base content of the soil; however small this change may be, it must affect the pH value of the soil. Although this change may not be material, from the practical point of view, its theoretical significance must be recognised.

The problem of finding isohydric pH values resolved itself, in the first instance, to the choice of a series of buffer mixtures, the acid-salt proportion of which could be easily ascertained and any change readily detected. Boric acid-borate and acetic acid-acetate mixtures proved useful for the purpose; the former covered the range between pH 7.8 and 10, and the latter between pH 3.7 and 6.

A mixture of acetate-acetic acid or of borate-boric acid could be easily analyzed by titrating with standard acid, and the pH value of any mixture could be ascertained from the titration curve. In tables 1 and 2 are given pH values of K-acetate-acetic acid and K-borate-boric acid mixtures. These

data, when plotted, give smooth curves from which any intermediate value can be interpolated. Thus any change in the pH value of these buffers can be measured by titrating before and after shaking with the soil. Since any increase or decrease in the basic portion of the buffer is brought about by a corresponding change in the exchangeable base content in the soil, and since the pH value of the soil and that of the buffer have been equalized by shaking, the final pH value of the mixture, as determined by titration and interpolation from the curve, gives the pH value of the soil resulting from a certain change in its base content, which, in turn, is given by the change in the acid titration value of the buffer on shaking with the soil. Thus by using a series of buffers, a number of values are obtained representing increasing changes in the exchangeable base content and the corresponding changes in the pH value of the soil. These values when plotted give a smooth curve, which may be called the isohydric titration curve of the soil. From this curve

TABLE 1

Composition of acetate-acetic acid buffers and their pH values

pH	3.72	4.05	4.27	4.45	4.63
Acetic acid, 0.2 *N* ..... *cc.*	90	80	70	60	50
K-acetate, 0.2 *N* ..... *cc.*	10	20	30	40	50

TABLE 2

Composition of boric acid—KCl—KOH buffers and their pH values

25 cc. of 0.2 *N* boric acid and 0.2 *N* KCl mixture + *x* cc. of 0.2 *N* KOH diluted to 100 cc.

pH	7.8	8.0	8.2	8.4	8.6	8.8
KOH (*x*)	1.32	2.0	2.95	4.27	6.0	8.2
pH	9.0	9.2	9.4	9.6	9.8	10.0
KOH (*x*)	10.7	13.35	16.0	18.425	20.4	21.95

is interpolated the pH value of the buffer which would undergo no change in its titration value. Since at this point the soil obviously would undergo no change in its base content either, this point represents the isohydric pH value of the soil. From the isohydric titration curve, the buffer capacity of the soil is obtained by noting the change in its base content required to produce a unit change in pH value. The lime requirement of the soil to any pH value could be easily obtained from the same titration curve.

For standardizing the working conditions of the method outlined, the following preliminary determinations had to be made:

Effect of time of shaking on the equilibrium between soil and buffer solution.
Effect of soil-buffer ratio.
Fate of the borate ion.

The results of these preliminary experiments showed that equilibrium is attained in 2 hours, longer shaking up to 48 hours making no appreciable

difference; soil-buffer ratios ranging from 1:20 to 1:5 gave practically the same result; and the concentration of the borate ion remained the same before and after shaking of the buffer with the soil.

DETAILED DESCRIPTION OF THE METHOD

Stock solutions of potassium acetate-acetic acid and potassium borate-boric acid of the following pH values are made: 4, 5, 6, 8, 9, 10. Two hundred

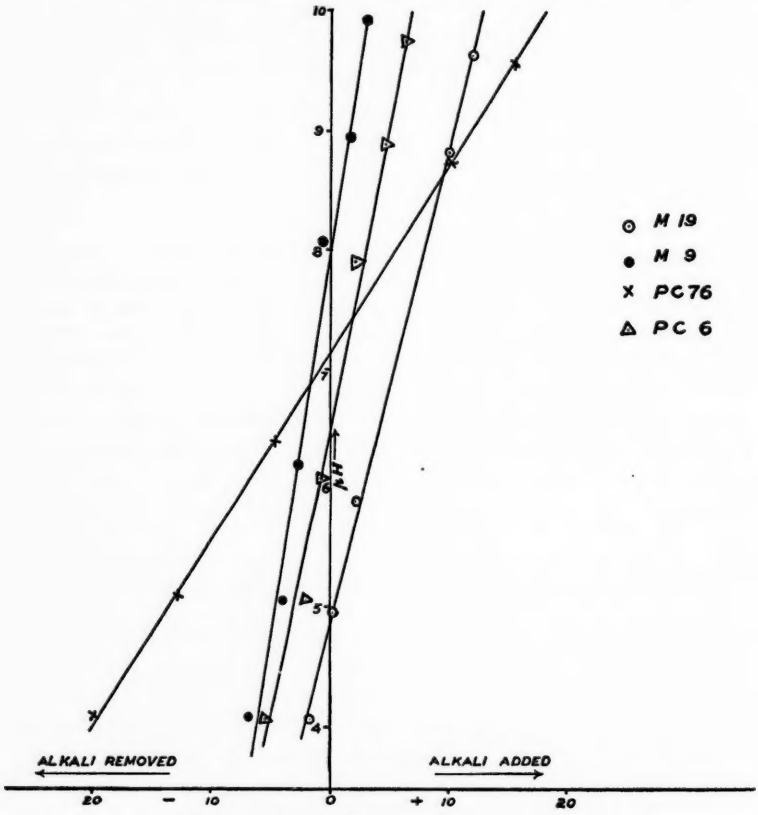

FIG. 1. ISOHYDRIC TITRATION CURVES OF SOILS

cubic centimeter portions of these solutions are shaken for 2 hours with 10-gm. portions of the soil, and the suspensions are filtered. The filtrates are titrated with standard acid, methyl orange being used as indicator. For the amount of acid required, the pH value is read from the curve. Assuming that when the state of equilibrium is reached, the soil and the buffer are isohydric with respect to hydrogen-ion concentration, and assuming that

TABLE 3

The pH values of various soils by different methods

SOIL NO.	ANTIMONY ELECTRODE, pH VALUE	QUINHYDRONE, pH VALUE	ISOHYDRIC, pH VALUE	BUFFER CAPACITY	CLAY CONTENT	BUFFER CAPACITY PER 100 GM. OF CLAY
				m.e.	*per cent*	*m.e.*
1	7.3	7.39	6.8	3.0	32.2	9.32
2	7.5	7.26	7.3	2.6	13.76	18.9
3	7.6	7.4	7.5	2.4	20.6	11.66
4	7.6	7.59	7.65	2.2	8.7	25.28
5	7.9	7.94	7.95	4.0	11.46	34.90
6	8.1	8.07	8.6	5.0	16.0	31.26
7	7.9	8.06	8.4	3.4	13.9	24.46
8	7.5	7.36	8.0	5.2	29.8	17.44
9	7.6	....	8.02	2.8	9.26	30.24
10	7.0	7.27	6.9	4.0	25.26	15.84
11	7.5	7.69	8.1	3.6	19.1	18.84
12	6.8	7.09	6.65	4.4	18.34	24.0
13	7.3	7.13	7.3	2.4	8.98	26.72
14	7.6	7.42	7.05	2.4	15.8	15.18
15	7.7	7.86	8.0	3.0	25.68	11.68
16	7.8	....	8.3	2.4	5.84	41.1
17	6.7	6.08	6.6	2.0	14.6	13.7
18	5.6	6.08	5.0	4.0	33.28	12.02
19	5.9	....	4.85	5.2	27.76	18.74
20	7.5	6.67	6.55	2.0	20.72	9.66
21	7.8	....	7.8	2.6	8.94	29.08
22	8.0	7.31	7.6	4.2	2.32	181.04
23	8.0	7.20	7.65	3.6	16.32	22.06
24	7.5	7.19	7.5	1.4	8.86	15.8
25	8.0	7.64	7.75	4.2	15.42	27.24
26	7.7	6.98	6.65	2.8	19.58	14.3
27	7.7	7.81	7.75	2.4	11.96	20.06
28	7.2	7.38	7.0	2.0	11.9	16.8
29	7.7	8.24	7.6	3.0	10.88	27.58
30	7.0	7.33	6.8	3.2	18.78	17.04
31	6.5	7.26	6.85	2.0	8.32	24.04
32	7.0	7.44	7.0	2.6	22.9	11.36
33	7.6	8.32	8.45	3.6	15.98	22.52
34	5.1	5.12	5.05	2.4	6.9	34.78
35	5.2	5.26	5.15	2.8	22.84	12.26
36	5.2	5.05	5.05	2.8	5.38	52.04
37	6.6	7.68	8.05	5.6	8.02	69.82
38	7.6	7.69	7.09	2.8	9.56	29.28
39	7.1	7.43	7.5	2.2	12.8	17.18
40	5.2	....	5.4	5.2	47.04	11.06
41	5.8	....	5.85	5.6	48.32	11.58
42	5.7	6.48	5.7	5.0	19.1	26.18
			Humus soils			
		GLASS ELECTRODE				
76	...	6.7	7.18	13.2	31.04	42.52
78	...	6.49	6.6	4.6	28.30	16.26
79	...	6.39	6.65	3.0	28.98	10.36
81	...	6.95	7.35	14.0	44.22	31.66
86	...	6.4	6.3	8.6	30.48	28.22
87	...	6.33	6.35	9.2	33.68	27.32

the base lost or gained by the buffer represents a gain or loss by the soil, we know the gain or loss of base by the soil in reaching the isohydric pH value. Thus a series of values corresponding to the series of buffer solutions are obtained, which when plotted, give a smooth curve, from which the pH value corresponding to no change in the buffer is interpolated. The acetate-acetic acid buffers evidently could not be used for calcareous soils. For these, borate-boric acid buffers alone are suitable, and only the upper portion of the curve is obtained. The buffer capacity of the soils, which may be defined as the milligram equivalents of alkali per 100 gm. of soil required to produce a change of 1 unit on the pH scale, is easily read off the isohydric titration curve. The lime requirement of acid soils to any pH is calculated from the interpolated

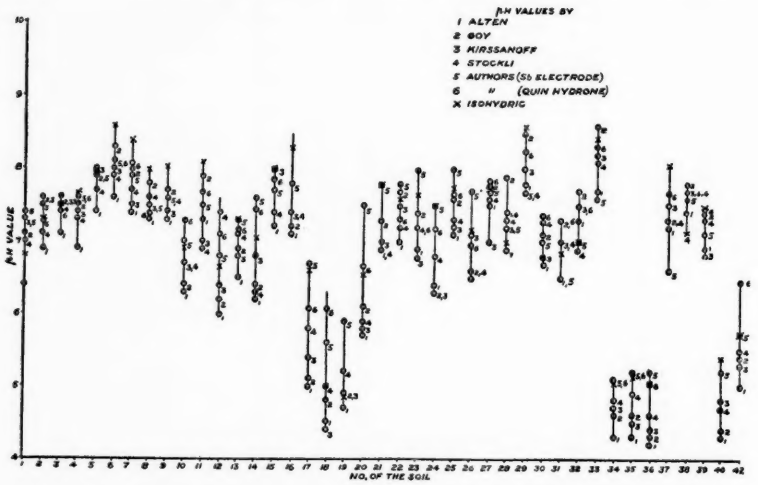

FIG. 2. THE pH VALUES OF SOILS AS DETERMINED BY DIFFERENT WORKERS AND BY DIFFERENT METHODS

value of the base equivalent corresponding to the desired pH value. A number of typical isohydric titration curves of soils are given in figure 1. It will be seen that most of the soils give a straight line relationship throughout the entire titration curve. In some cases, however, there is a slight curvature in the lower part of the curve, which is due to the presence of $CaCO_3$ in the soils. This curvature, however, does not affect the interpolation.

COMPARISON WITH OTHER METHODS

The difficulty of measuring the pH value of soils by the usual methods has already been pointed out. The agreement between the soil reaction determined by any of the standard methods and the isohydric pH value, therefore, can only be approximate. For comparison, the pH values were determined

in 1:5 soil-water ratio with the antimony electrode as well as with the quinhydrone electrode after shaking for 1 hour. The results are given in table 3. The pH values of these soils, except those of the humus soils, had been determined by four other workers under different sets of conditions. The values obtained by the other workers are not included in table 3, but they as well as the isohydric pH values are plotted in figure 2, which brings out clearly the wide variations that might be expected in pH measurements by the ordinary electrical method. The agreement between the isohydric pH values and the pH values determined by the antimony or quinhydrome electrode is better than that between the values determined by other workers. This better agreement might possibly be due to the fact that these three sets of values were determined in this laboratory on uniform samples under similar conditions whereas values determined by other workers were obtained on different samples, possibly under different sets of conditions. The necessity of specifying the conditions of such measurements is, therefore, quite obvious. It must be emphasized that the pH value of soil as determined by the electrical method is not a fundamental constant. The isohydric pH value, on the other hand, relates definitely to the state of saturation of the exchange complex and as such can define the soil much more satisfactorily than can the pH value determined by the usual methods in water suspension.

BUFFER CAPACITY OF SOILS

Buffer capacity of soils may be defined as the milliequivalents of alkali per 100 gm. of soil required to increase its pH value by 1 unit on the pH scale. Values for buffer capacity are included in table 3. If the buffer action of a soil be ascribed to clay, then it appears of interest to compare the buffer capacity of soils on the basis of clay, i.e., buffer capacity per 100 gm. of clay. These values included in table 3 are useful for comparing the types of clays in different soils.

pH VALUES OF HIGHLY ALKALINE SOILS

Highly alkaline soils form a class by themselves. They invariably contain a certain amount of sodium carbonate or bicarbonate, on account of which it is difficult to determine their isohydric pH value by the method outlined in this paper. They are, however, already in equilibrium with a sodium carbonate-bicarbonate buffer solution which determines their pH value. The reaction of such soils can be easily determined by finding the concentration of sodium carbonate-bicarbonate and then interpolating the pH value from the titration curve of NaOH with CO_2. The pH values of various mixtures of carbonate-bicarbonate at different concentrations were determined with the glass electrode, both in water and in 0.1 *N* KCl solution, the values in KCl solutions being uniformly lower by 0.2 pH than those in water. The following relation was found to hold between pH values and the carbonate-

bicarbonate ratio as well as the total concentration of the mixture in 0.1 *N* KCl solution:

$$\text{pH value} = 8.67 + 0.018\,A - 0.0032\,B$$

when

B = cc. of 0.1 *N* alkali (carbonate + bicarbonate) in 100 cc. solution
A = per cent of Na_2CO_3 in B.

From this relation the pH value of any alkali soil is determined by shaking the soil with 0.1 *N* KCl solution, filtering, and analyzing an aliquot of the filtrate for carbonate-bicarbonate. Since the pH value in KCl is lower than that in water solution by 0.2 pH, this amount is added to the pH value obtained from the formula to correspond to the pH value in water solution.

TABLE 4

The pH values of alkali soils calculated from carbonate-bicarbonate ratio and determined directly (soil: water ratio 1:5)

SOIL NO.	0.1 *N* CARBONATE	0.1 *N* BICARBONATE	pH CALCULATED (WATER SOLUTION)	pH FOUND (Sb ELECTRODE)
	cc.	cc.		
P.C. 57	0.6	0.7	9.70	9.8
P.C. 58	14.1	9.83	9.85	10.08
P.C. 59	0.0	1.0	8.87	8.66
P.C. 60	36.8	16.4	9.95	9.94

In table 4 are given pH values of certain typical alkali soils determined by the electrical method using the antimony electrode and the values obtained by titrating the 0.1 *N* KCl solution extract for carbonate-bicarbonate. The agreement is sufficiently close to illustrate the general principle involved. It might be pointed out that the method is not applicable unless the amount of sodium carbonate-bicarbonate in the soil is sufficiently large. For soils containing little or no free alkali carbonate-bicarbonate the usual isohydric method described in this paper is suitable.

SUMMARY

Isohydric pH value of a soil is defined as the pH value of a buffer solution which shows no change in reaction on coming into contact with the soil and which consequently brings about no change in the base content of the soil.

A method of determining isohydric pH value, titration curve, buffer capacity, and lime requirement of soils is described.

MICROBIAL ACTIVITIES IN SOIL: IV. MICROFLORA OF DIFFERENT ZONAL SOIL TYPES DEVELOPED UNDER SIMILAR CLIMATIC CONDITIONS[1]

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In transitional areas between two different soil zones, it is not uncommon to find different zonal types of soil developed from the same parent material under similar climatic conditions. A forest type of soil may occur adjacent to a prairie type of soil, each possessing its own particular vegetative cover and inherent soil characteristics. The character of the humus formed from each specific type of vegetation under these conditions is generally believed to be chiefly responsible for the development of divergent soil properties. Organic materials and their mineralization may profoundly affect the physical, chemical, and biological properties of the soil, and consequently such factors as the formation, fertility, and erosibility of the soil. A thorough knowledge of the soil microflora and its activity, which are responsible for the mineralization of organic materials and the formation of humus, is, therefore, of fundamental importance.

The influence of different types of humus and of dissimilar soil characteristics on the nature and activity of the microflora in two zonal soil types similar in mechanical composition but developed under different climatic conditions was amply demonstrated in a previous publication (20). The chief purpose of the work presented in this paper was to ascertain the nature and seasonal activity of the microflora, in its natural environment, of two different zonal soil types developed from the same parent material under similar climatic conditions.

EXPERIMENTAL PROCEDURE

Three virgin areas, two consisting of Palouse silt loam and the other of Helmer silt loam, were selected for this study. Both the Palouse and Helmer soils have developed on fine-textured loessial material under similar climatic conditions. The native vegetation on the Palouse soil is composed chiefly of tall bunch grass mixed with some bushy growth consisting of wild roses, snowberries, and buckbrush. A very thin irregular layer of litter composed largely of grass vegetation in various stages of decomposition covers the soil.

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The native vegetation of the Helmer soil is chiefly coniferous forest growth consisting of yellow, white, and lodgepole pine, fir, spruce, and cedar, although according to Agee et al. (1) some areas support white pine almost exclusively. A layer of coniferous duff ranging from 0.5 to 1.5 inches in thickness covers the soil and is not sharply demarcated from the mineral soil below, but merges gradually into it.

The mean annual temperature for the localities represented by these virgin areas is 47°F. The mean monthly minimum temperature, which occurs in January, is 22°, and the mean maximum monthly temperature, which occurs in July, is 82°. The extremes in temperature range from −20° in February to 104° in July. The mean annual precipitation for the virgin Palouse soil situated near Pullman, Washington, is 20.73 inches. The best figure available for the mean annual precipitation for the other two virgin areas represented by the Palouse and Helmer soils near Troy, Idaho, is 22.51 inches. This figure was obtained from the climatological data at Moscow, Idaho, which is situated 10 miles straight west of Troy and at approximately the same elevation. More than 60 per cent of the precipitation in these localities occurs during the winter months between November 1 and April 1. Snow lies on the ground intermittently for periods ranging from 2 to 6 weeks between December 1 and March 15. Very little precipitation occurs during the months of July, August, and September.

Weather conditions permitting, samples of soil were taken in the field at fairly regular intervals between February, 1935, and May, 1936, at depths of 0–0.5 inches, 0.5–4 inches, and 4–10 inches. The coarse rubbish on the surface of the soil was removed, and four auger borings obtained from as many permanently established centers scattered over an area of about 2 square rods were composited for each sample. The borings were made near the same local points at each sampling period. Plate counts were made for bacteria, actinomyces, and fungi in the samples taken at each depth; and for *Azotobacter*, aerobic cellulose-decomposing bacteria, and anaerobic nitrogen-fixing bacteria in composite samples of the three depths. The pH values and the redox potentials were determined on the air-dried samples taken at each depth.

The bacteria and actinomyces were grown on albuminate agar adjusted to pH 7.2, and the fungi, on potato dextrose agar adjusted to pH 3.5 by addition of sterilized 0.4 *N* citric acid. These media are described by Fred and Waksman (10, p. 9–18). The *Azotobacter*, aerobic cellulose-decomposing bacteria, and anaerobic nitrogen-fixing bacteria were determined by spreading suitable quantities of finely pulverized soil on silica gel plates. Winogradsky's (27) nutrient solutions were used for the growth of Azotobacter and anaerobic nitrogen-fixing bacteria, anaerobic conditions for the latter being produced with pyrogallic acid and potassium hydroxide. Waksman's (22) nutrient solution, together with filter paper, was used for the development of the aerobic cellulose-decomposing bacteria. All plates were incubated at 28°C.

The pH values and the redox potentials were determined by means of a glass

electrode apparatus, a suspension of 1 part of soil to 5 parts of distilled water being used for the pH determinations, and mixtures of 5 gm. of soil and 10 cc. of 0.1 *N* H_2SO_4 according to the method of Peech and Batjer (16) being used for the redox potentials. The nitrogen was determined by the official Kjeldahl (3, p. 5–16) method, and the organic carbon in the soil and in the soil extracts, by the wet combustion method of Friedemann and Kendall (11).

EXPERIMENTAL RESULTS

Seasonal variations in microbial activity

Since moisture and temperature, as well as the food supply, affect biological activity fundamentally, numbers and activity of different kinds of microbes should follow, more or less closely, seasonal temperature and moisture changes in the soil. One should expect the largest numbers in late spring and early fall when temperature and moisture conditions are most nearly optimum, and the smallest numbers in winter and summer, because of low temperatures in winter and excessive dryness and high temperatures in summer. This assumption is not always borne out by facts. Snow (18), Cobb (6), Fehér (9), and Brown and Halversen (5) have presented evidence of extreme variability in the microbial population in the soil in different seasons. Waksman (21) found that microbial peaks vary with the type of soil and the depth, but he did not correlate these with the moisture content of the soil. Cutler, et al. (7) obtained maximum numbers in November, minimum numbers in February or March, and a secondary peak at the end of June. These did not correlate with seasonal changes in soil moisture, rainfall, or temperature. Erdman (8) found that the seasonal fluctuations in numbers in two years were not the same; although the maximum for both years was in June and the minimum in August, the count was low in February or March one year, and a second peak occurred in these same months the other year.

The data on numbers of bacteria, actinomyces, and fungi found in different seasons and at different depths in the Palouse and Helmer soils described in the foregoing section are presented in figures 1 to 3. They supply sufficient evidence for only a general statement regarding the effect of seasonal variations on numbers of soil microbes. Microbial peaks were manifested in the spring, especially during April, 1935, and in late fall and early winter during the months of October to January. With certain exceptions these peaks occurred at the same time at the different depths of the soil and were more or less of the same order for the different groups of microbes. The data in table 1 and figure 4 show that the moisture and temperature regimes were more nearly at optimum during the periods of maximum microbial numbers than during the intervals of minimum numbers. When temperatures became higher and the soil dryer, as in the month of July, or when temperatures dropped very low, as in the winter months, the numbers of microbes decreased. This decrease was generally less pronounced in the winter months when an ample supply of moisture was available than in the summer months when both high tempera-

tures and low moisture contents combined in inhibiting microbial activity. It may be noted also that the numbers of microbes in 1936 were not nearly so large as those at corresponding times in 1935, bearing out the observation of

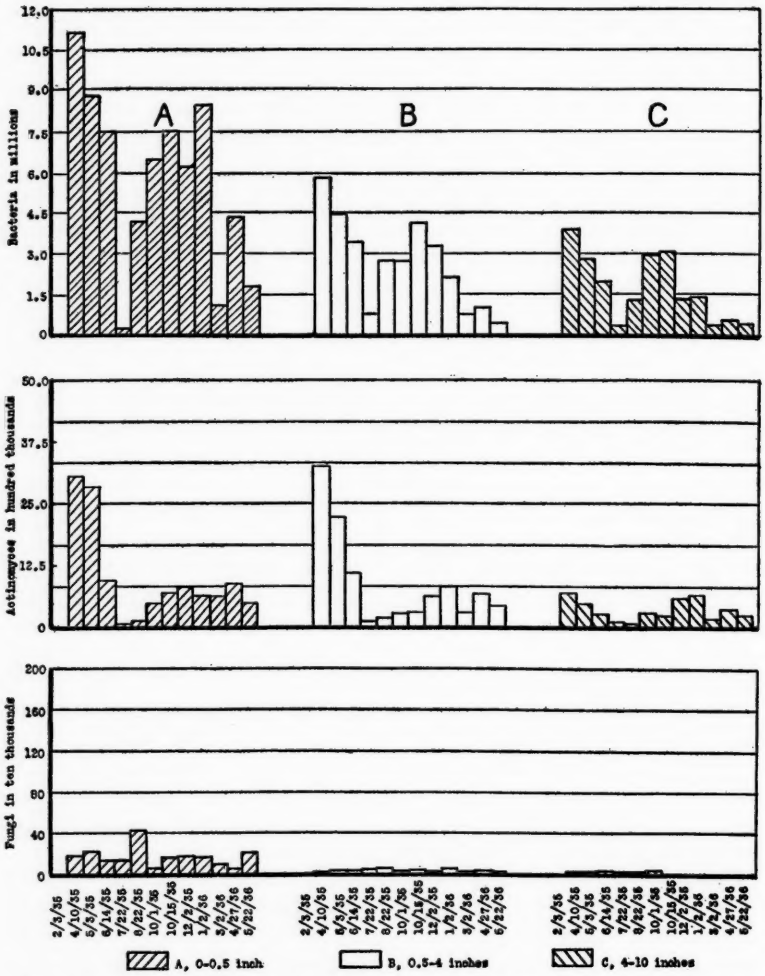

FIG. 1. NUMBERS OF BACTERIA, ACTINOMYCES, AND FUNGI PER GRAM OF DRY SOIL IN PALOUSE SILT LOAM (PULLMAN)

Erdman (8) that microbial peaks in two different years may vary. As indicated in table 1 and figure 4, the soil on the whole contained less moisture in 1936 during the months when samples were taken than at corresponding times

in 1935, and the temperatures in the early part of 1936 were somewhat lower than those at corresponding times in 1935. Both of these factors probably contributed to the differences in counts obtained.

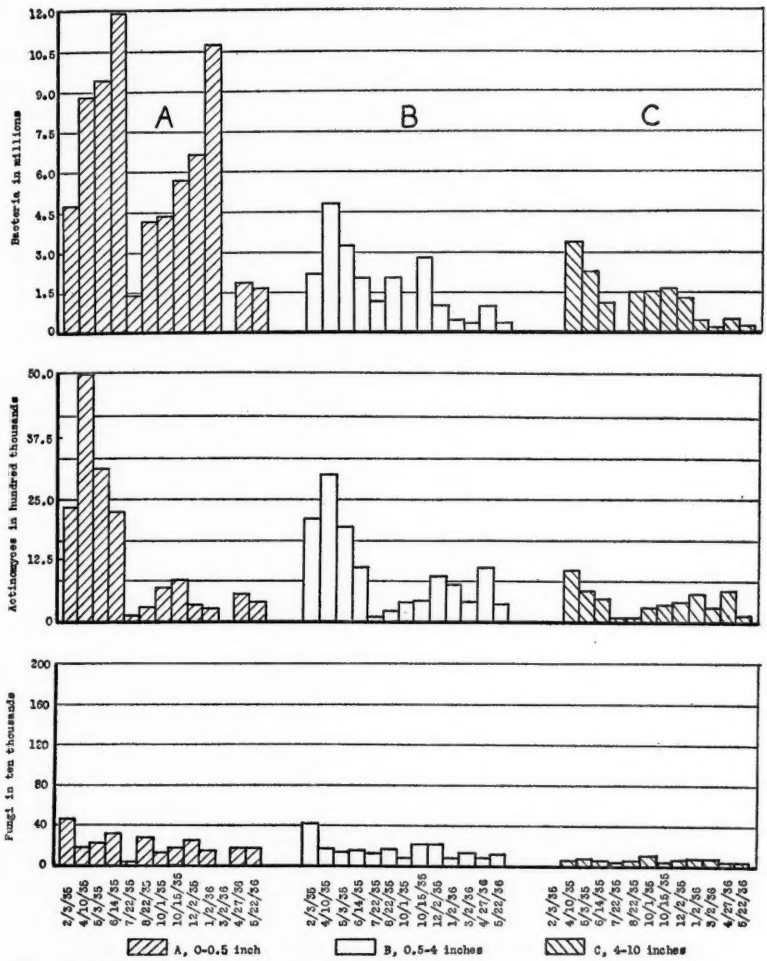

FIG. 2. NUMBERS OF BACTERIA, ACTINOMYCES, AND FUNGI PER GRAM OF DRY SOIL IN PALOUSE SILT LOAM (TROY)

Although figures 1 to 3 indicate in a general way microbial maxima in spring and fall and minima in summer and late winter, corresponding broadly with the observations of Waksman and Starkey (24, p. 64–65) and of Cobb (6), these maxima and minima are by no means absolute. Within any particular

season, variations occurred which cannot be explained by the available moisture and temperature data. Errors arising from sampling and analysis may account in part for some of these variations, so that only the larger broader seasonal

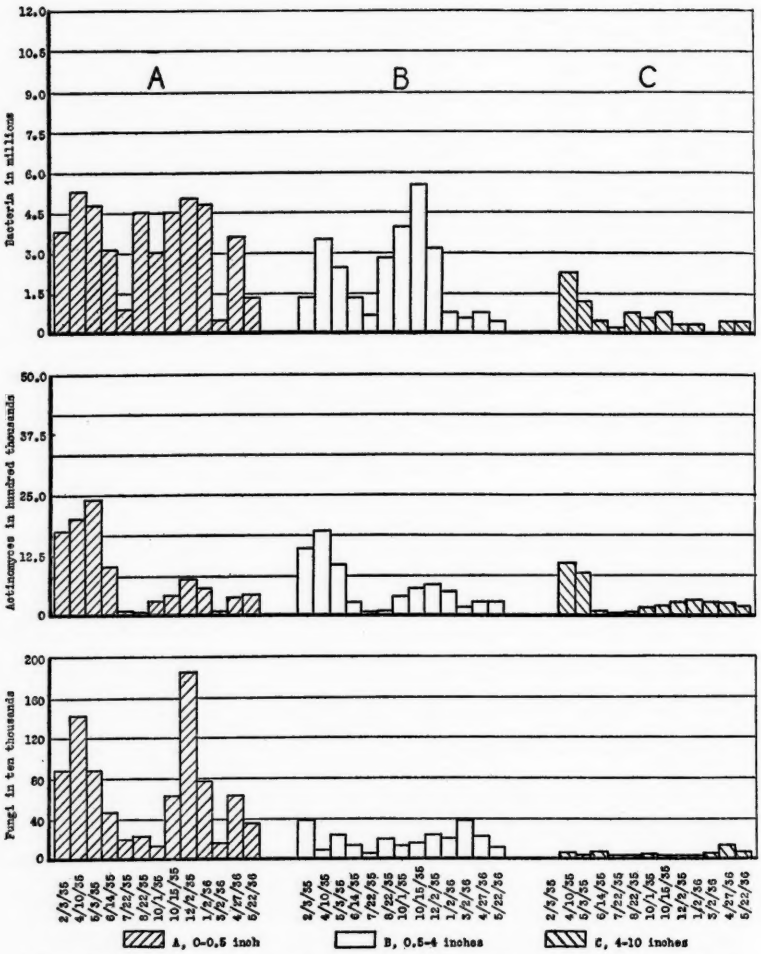

FIG. 3. NUMBERS OF BACTERIA, ACTINOMYCES, AND FUNGI PER GRAM OF DRY SOIL IN HELMER SILT LOAM

trends indicated by the microbial counts are consistent enough to warrant the mention they received.

The fact that numbers of microbes decrease with depth in the soil is commonly accepted and has been noted by Waksman (21), Cobb (6), and Snow

TABLE 1

Climatological data for Moscow, Idaho, and for Pullman, Washington

TIME	MEAN MONTHLY TEMPERATURE	MONTHLY MAXIMUM	MONTHLY MINIMUM	TOTAL PRECIPITATION	DATE OF SAMPLING	MAXIMUM TEMPERATURE	MINIMUM TEMPERATURE	PRECIPITATION
	°F.	°F.	°F.	inches		°F.	°F.	inches
Moscow, Idaho								
1935:								
January	30.6	52	−19	2.73				
February	35.3	52	17	1.06	3	50	34	0
March	35.8	64	9	2.55				
April	43.7	65	21	2.93	10	60	31	0
May	53.9	80	25	0.24	3	63	29	0
June	58.8	85	35	0.61	14	68	45	0.27
July	64.7	100	37	0.47	22	93	48	0
August	63.6	99	30	0.34	22	89	48	0
September	60.5	91	25	0.26				
October	46.3	86	2	1.25	1	83	38	0
					15	53	35	0
November	33.8	52	0	0.96				
December	31.4	45	13	2.59	2	40	18	0
1936:								
January	30.8	45	−2	5.12	2	41	32	0.83
February	16.4	49	−20	2.17				
March	36.6	61	16	1.92	2	56	35	0
April	50.4	85	11	0.52	27	59	38	0
May	58.0	91	34	0.86	22	65	42	0
Pullman, Whitman County, Washington								
1935:								
January	31.2	52	−13	2.57				
February	35.6	52	22	1.00				
March	36.1	64	21	2.36				
April	44.0	66	23	2.38	10	60	33	0
May	53.8	78	33	0.33	3	65	33	0
June	60.2	82	42	0.65	14	55	49	0.10
July	66.7	98	42	0.32	22	91	54	0
August	65.5	96	39	0.57	22	87	56	0
September	62.6	88	33	0.26				
October	47.4	82	4	0.95	1	80	50	0
					15	53	39	0
November	33.6	52	4	0.76				
December	31.2	45	16	1.96	2	29	22	0
1936:								
January	31.3	45	5	4.29	2	41	34	0.05
February	17.1	46	−13	1.87				
March	37.0	62	17	1.85	2	59	36	0.02
April	50.7	86	5.5	0.43	27	60	39	0.02
May	59.3	91	37	1.17	22	66	45	0

(18), as well as by many other investigators. The data in figures 1 to 3 show this trend very distinctly with respect to the numbers of bacteria, actinomyces, and fungi even at the relatively shallow depths sampled. The bacteria and fungi decreased more rapidly in numbers with depth than did the actinomyces. As may be noted by comparing the soil moisture and the precipitation data in table 1 and figure 4, no consistent relationship existed between reduction in numbers of organisms with depth and changes in soil moisture content with depth, but there was a distinct correlation between the reduction in numbers of organisms with depth and the organic food supply, which was greatest at the surface and decreased sharply with depth. The difference in the amount and quality of air from the surface to the lower depth probably also contributed to the decrease in numbers with depth. The bacteria and fungi were more responsive to these factors than were the actinomyces, particularly in the surface 0.5-inch layer as compared with the 3.5-inch layer below it. On an average, the 0.5–4-inch layer yielded less than half as many bacteria and fungi, and

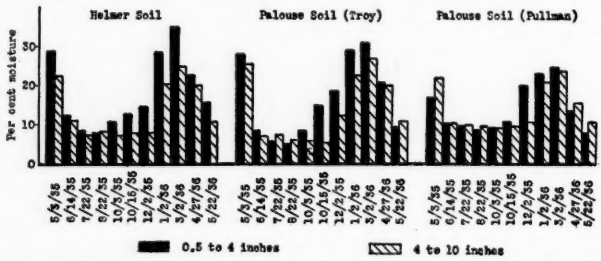

FIG. 4. PERCENTAGES OF SOIL MOISTURE BASED ON DRY WEIGHT AT DIFFERENT DEPTHS AND SAMPLING PERIODS

The moisture content of the surface 0–0.5-inch layers was not determined because of insufficient quantities of duff or litter.

about three-fourths as many actinomyces as the surface 0.5-inch layer. In the 4–10-inch layer the average numbers of bacteria and fungi ranged from 10 to 20 per cent, and those of the actinomyces from 30 to 35 per cent of the numbers in the respective groups in the 0.5-inch surface layers.

Effect of climatic factors and vegetative cover on microbial activity

Climatological data for Pullman, Washington, which are representative of the climatic conditions affecting the Palouse soil near Pullman, and those for Moscow, Idaho, which represent the climatic conditions affecting the Palouse and Helmer soils near Troy, are recorded in tables 1 and 2. The monthly precipitation; the monthly mean, maximum, and minimum temperatures; and the dates of sampling, as well as the precipitation and the maximum and minimum temperatures occurring on these dates, are presented in table 1. The figures on annual precipitation and mean annual temperatures for the years 1930 to 1935 inclusive are given in table 2.

The data on annual and monthly precipitation indicate a slightly more humid climate for the soils near Troy, Idaho, than for the Palouse soil near Pullman, Washington. Even this small difference in climatic conditions is reflected by the microbial activities in the two Palouse soils, as may be noted from the data in figures 1 to 3 with respect to total numbers of organisms and numbers of bacteria, actinomyces, and fungi separately for the three depths sampled. Although the total numbers and the percentages represented by each of the three groups of microbes fluctuated greatly at different times, the total numbers as well as the percentages of actinomyces and also of fungi in the two lower depths were greater, on the average, in the Palouse soil near Troy than in the Palouse soil near Pullman. The exception for the percentage of fungi in the surface layer of these two soils is due in part to low numbers of bacteria or to more than usual fluctuations in numbers of actinomyces and fungi at certain times.

TABLE 2

Mean annual temperature and total annual precipitation for the years 1930 to 1935 inclusive

YEAR	MOSCOW, IDAHO*		PULLMAN, WASHINGTON†	
	Temperature	Precipitation	Temperature	Precipitation
	°F.	*inches*	°F.	*inches*
1930	46.4	19.46	46.9	18.88
1931	47.7	21.01	47.7	20.27
1932	46.8	27.14	47.4	22.11
1933	47.5	29.63	48.3	26.62
1934	51.6	22.47	52.2	19.48
1935	46.4	15.99	47.3	14.11

* Elevation 2,628 feet.
† Elevation, 2550 feet.

The effect of the difference in vegetative cover of the Palouse and Helmer soils is clearly expressed by the types of microflora and the numbers of organisms in the various groups. As may be noted by comparing the data in figures 2 and 3, the bacteria, although relatively plentiful, were less numerous and the fungi much more numerous in the 0.5-inch layer and also to some extent in the 0.5–4-inch layer of the Helmer soil than those at the same depths in the Palouse soil. The actinomyces were more numerous at all depths in the latter soil, although the differences between the two soils in percentages of actinomyces on the basis of total microbial population are not very significant. The higher numbers of fungi in the Helmer soil, which bears coniferous trees, as compared with those in the two Palouse soils, which are covered with grass vegetation, is in accord with established conceptions. The comparatively large numbers of bacteria and actinomyces in the Helmer soil are not unusual. Many investigators, including Waksman et al. (25), Powers and Bollen (17), Aquino (2), and Greene (13), obtained similar results.

Large numbers of aerobic cellulose-decomposing bacteria have been found in many soils by various investigators. Anaerobic nitrogen-fixing bacteria also have been observed to be relatively numerous in certain soils. Willis (26) and Bokor (4) found rather large numbers in acid soils. These two groups of organisms, therefore, may play an important part in the biological processes in certain soils. The numbers of aerobic cellulose-decomposing bacteria and

TABLE 3

Aerobic cellulose-decomposing bacteria per gram of soil in the surface 10 inches

DATE OF SAMPLING	HELMER SOIL	PALOUSE SOIL (TROY)	PALOUSE SOIL (PULLMAN)
2/ 3/35	0	20	
4/10/35	0	0	5
5/ 3/35		37	150
6/14/35	45	50	60
7/22/35	0	115	67
8/22/35	112	75	150
10/ 1/35	12	62	45
10/15/35	35	22	50
12/ 2/35	2	70	70
1/ 2/36	50	210	230
3/ 2/36	7	5	12
4/27/36	146	246	120
5/22/36	23	63	53

TABLE 4

Anaerobic nitrogen-fixing bacteria per gram of soil in the surface 10 inches

DATE OF SAMPLING	HELMER SOIL	PALOUSE SOIL (TROY)	PALOUSE SOIL (PULLMAN)
2/ 3/35	0	0	
4/10/35	50	100	250
5/ 3/35	5	20	17
6/14/35	35	30	150
7/22/35	27	40	137
8/22/35	25	80	75
10/ 1/35	25	17	67
10/15/35	100	40	50
12/ 2/35	25	65	12
1/ 2/36	5	0	45
3/ 2/36	10	40	145

anaerobic nitrogen-fixing bacteria which were determined on composite samples of the three depths in each of the three soils investigated are recorded in tables 3 and 4, in which it is shown that these organisms were never very active. Their numbers fluctuated too greatly to warrant any conclusion with respect to seasonal trends or effect of climate and vegetation. The Palouse soil near Pullman had a somewhat larger population of anaerobic nitrogen fixers than did the other two soils, but the difference was not significant.

No *Azotobacter* were found at any time in any of the three soils, which ranged in pH values from 5.44 to 6.53 for the Helmer soil and from 6.18 to 7.13 for the Palouse soils, the variations depending on the depth in the soil and the season. In a study of the *Azotobacter* population in a number of Helmer soils which varied in pH value from 5.66 to 7.2, Gibbs and Batchelor (12) found these organisms in 24 per cent of the soils. As reported in a previous publication (19) these organisms were present also in certain soils with a pH value of 5.5 or less and in cultivated Palouse silt loam located near the area of virgin Palouse soil at Pullman. Soil reaction alone does not explain the absence of *Azotobacter* in the Palouse and Helmer soils. Since the publication of the aforementioned study of *Azotobacter*, which also reports the presence of maximum

TABLE 5

pH and Eh values of the various soils at different times during the year

DATE OF SAMPLING	HELMER SOIL			PALOUSE SOIL (TROY)			PALOUSE SOIL (PULLMAN)		
	0–0.5 inches	0.5–4 inches	4–10 inches	0–0.5 inches	0.5–4 inches	4–10 inches	0–0.5 inches	0.5–4 inches	4–10 inches
				pH Values					
5/ 3/35	6.53	6.53	6.16	6.53	6.46	6.32	6.78	6.83	6.70
7/22/35	5.90	6.15	6.00	6.30	6.40	6.40	6.51	6.93	6.93
10/ 1/35	5.82	6.06	6.25	6.49	6.30	6.26	6.98	6.76	6.76
4/27/36	6.28	6.21	6.15	6.18	6.43	6.28	6.76	6.74	6.59
				*Eh Values**					
5/ 3/35	754.8	821.0	808.0	711.2	808.8	836.0	715.4	786.0	798.0
7/22/35	633.4	763.0	731.0	608.8	788.8	801.8	605.4	756.4	778.4
10/ 1/35	627.5	816.0	845.5	620.1	798.0	927.8	617.9	783.8	803.0
4/27/36	622.0	779.5	794.6	616.5		782.7	609.0	767.4	800.4

* The Eh values are the oxidation-reduction potentials calculated to a standard pH value of 2, using the correction factor of 80 millivolts per change of 1 pH unit, according to Peech and Batjer (16).

numbers of these organisms in Palouse silt loam in late fall and early spring and very few or none in the summer months, unpublished results of periodical determinations of *Azotobacter* in this soil show that for no accountable reason these organisms have disappeared completely. This condition applied to both the virgin and the cultivated Palouse soils and apparently also to the virgin Helmer soils. Reaction is not the limiting factor, and no data are as yet available which may explain the absence or disappearance of the *Azotobacter* from these soils.

Soil reaction, redox potentials, and humus content in relation to microbial activity

The pH and Eh values of the samples of the Helmer and the two Palouse soils taken at the three depths were determined at each sampling. Because of

the relatively small differences in values obtained during different times of the year, only the results of a few typical determinations are given in table 5.

Forest soils, particularly near the surface, are reputed to be more acid than grassland soils, partly because of greater humidity but particularly because of the peculiar nature of the organic residues. The nature of the organic residues returned to the Helmer soil probably is chiefly responsible for the lower pH values of this soil as compared with those of the Palouse soil in the same locality. Probably the fungus population, which was larger in the Helmer soil than in the Palouse soils, was favored also by the more acid reaction. The slightly lower pH values indicated for the Palouse soil near Troy than for the one near Pullman probably is due to a slightly more humid climate in the Troy area. This, rather than the difference in soil reaction, probably accounts for the more active microbial development noted in the Palouse soil near Troy. Cobb (6) lists a number of investigators who found that small changes in soil reaction have no apparent relationship to the numbers of microbes present in the soil although different types of microbes may be strongly influenced by reaction. The data in table 5 indicate no apparent relationship between depth in the soil and reaction or seasonal variations in pH values.

The method of Peech and Batjer (16), slightly modified, was used for the determination of the redox potentials of the soils in this investigation. Instead of keeping the soil-acid mixture standing for 24 hours with intermittent shaking, as suggested by Peech and Batjer, we reduced the time factor to 8 hours and allowed the soil-acid mixture to stand in contact with the electrode for 20 minutes before making the readings. A platinum electrode was used for the determinations of the redox potentials, and a glass electrode for the pH values. Preliminary trials with different soils resulted in a satisfactory equilibrium of the system by this procedure. The Eh values recorded in table 5 were obtained by this procedure and represent the oxidation-reduction potentials calculated to a standard pH value of 2.

The most significant differences in the Eh values are those between the 0–0.5-inch layers and the two layers below them. In every case the Eh value of the surface, highly organic layer was definitely lower than the Eh values the two underlying layers. The differences in the values of the other two layers of the various soils and in different seasons are not significant. No correlation could be established between the differences in redox potentials and the differences in microbial activity in the various soils.

Heintze (14) states that under normal conditions the factors responsible for oxidation-reduction equilibriums are the reserves of oxidized and reduced materials rather than the temporary occurrence of highly active substances. From numerous waterlogging experiments he found marked decreases in Eh values for soils known to contain organic matter capable of rapid decomposition, as soon as soil moisture content and reaction become favorable. Both the Helmer and Palouse soils contain organic materials which are susceptible to rapid decomposition under favorable conditions, as will be pointed out in the

following paper in this series. It is not presumptuous, therefore, to suppose that in the highly organic surface layer of these two soils are present reducing organic compounds which are responsible for the observed low Eh values.

Data on Melbourne and Palouse soils reported in the preceding paper of this series (20) indicate that although the Melbourne soil, which bears forest vegetation, contains much more humus than the Palouse soil, which bears grass vegetation, the latter had the larger microbial population and by far the smaller number of fungi. A similar microbial relationship was manifested under field conditions in the Palouse and Helmer soils near Troy. As may be noted from the data in table 6, the humus and the surface residue of the Palouse soil contain larger amounts of combined water-soluble and H_2SO_4-soluble carbon, and less H_2SO_4-insoluble carbon than did the same substances of the Helmer soil. Evidently the nature of the humus rather than the amount within certain limits is the more influential in determining the type and numbers of microbes. The fact that organic residues and humus derived from forest

TABLE 6

Organic carbon and nitrogen contents of the organic residue layer and of the surface 10 inches of the Palouse and Helmer soils near Troy, Idaho

SOIL	ORGANIC C	TOTAL N	C/N	FRACTIONS IN PER CENT OF TOTAL CARBON		
				Water-soluble C	H_2SO_4-soluble C	H_2SO_4-insoluble C
	per cent	*per cent*				
Palouse soil	3.46	0.2091	16.5	3.38	28.01	65.43
Palouse soil litter	32.64	0.7035	46.4	5.40	51.73	37.56
Helmer soil	2.32	0.1001	23.2	3.19	26.44	69.88
Helmer soil duff	36.69	0.5782	63.5	6.92	27.03	62.08

vegetation were found to be favorable for fungal growth is in accord with established conceptions as mentioned previously.

The marked difference in humus content of the Palouse and Helmer soils, which have developed from identical parent materials and under practically identical climatic conditions, slopes, and exposures, is noteworthy. One would expect at least as much annual production of vegetative growth from forest vegetation as from grass vegetation under such conditions, because loss of moisture by evaporation is less under forest cover than that under grass cover, and tree roots are capable of obtaining water from lower depths than those accessible to grass roots, provided the subsoil is permeable to roots, as is the case in these two soils. Virtually all the vegetative growth including roots and top growth is eventually returned to the soil under virgin conditions. The Helmer soil, as pointed out previously, has a duff cover ranging from 0.5 to 1.5 inches in thickness, whereas the Palouse soil has only a very thin layer of litter covering the surface irregularly. This indicates that the organic residue

of the top growth on the forest soil has a tendency to accumulate and that of the top growth on the grassland soil is decomposing as rapidly as it is being formed. Evidently not all the humus in the soil is derived from the top growth of the vegetative cover. Pedologists, in general, believe that the plant roots, especially in grassland soils, play a more important part in soil organic matter relationships than has hitherto been recognized.

Information in the literature regarding the quantities of organic residues added annually to the surface of soils by different kinds of native vegetation

TABLE 7

Grass vegetation on the Palouse soil and root distribution in the Palouse and Helmer soils

SAMPLING AREA	SURFACE GROWTH		ROOT DISTRIBUTION			
	Oven-dry weight per square yard		Oven-dry weight per square foot			
	Palouse soil	Helmer soil	Palouse soil		Helmer soil	
			0–4 inches	4–10 inches	0–4 inches	4–10 inches
	gm.		*gm.*	*gm.*	*gm.*	*gm.*
1	143.5		202.5	53.5	41.6	86.0
2	147.5		110.5	32.7	25.8	21.5
3	120.9		100.0	73.0	42.3	40.0
4	109.9		101.0	27.5	71.9	62.5
5	145.7		24.5	16.5	57.4	38.0
Total	667.5		538.5	203.2	239.0	248.0
Average	133.5		107.7	40.6	47.8	49.6
Equivalent in tons per acre	0.711	1.37*	5.16	1.95	2.29	2.38
Character of the root material			Mostly fine matty, tough roots, mixed with some larger herbaceous and shrub roots. Uniformly distributed in both layers.		Some small, fine roots, but major part of the weight due to larger tree and shrub roots. Irregularly distributed in both layers.	

* Based on averages of the data given by Waksman (23, p. 221–226).

is not extensive, and that with respect to the amount of root material present at different depths in forest and grassland soils is scarce indeed. Waksman (23, p. 221–226) refers to a number of investigators whose results show an average of about 2,500 or 3,000 pounds an acre of tree residues added annually to the surface of forest soils. It was not convenient to determine the amount of tree residues annually returned to the Helmer soil, but judged from the nature of the forest growth on this soil, the amount probably would come close to average figures. An attempt was made to determine the amount of top growth produced annually on the Palouse soil and also of the root distribution

at the depths of 0 to 4 inches and 4 to 10 inches in both the Palouse and the Helmer soils. Five sampling areas bearing typical vegetative covers of grass and forest growth respectively were selected. The size of sampling spots for the grass vegetation on the Palouse soil was 1 square yard, and that for the root distribution in both the Palouse and the Helmer soils was 1 square foot. The grass vegetation was cut close to the ground and oven dried. The root materials were obtained by removing blocks of soil 1 square foot in size at the required depths. The roots were washed free from soil and oven dried. The results of these determinations are recorded in table 7.

Because of natural irregularities in the distribution of native plants, a considerable variation in the weight of root materials in different sampling spots was obtained, but the averages should be fairly representative of field conditions. On the basis of the average figures in table 7, it appears that the amount of top growth annually returned to the Helmer soil should be nearly twice the amount returned to the Palouse soil, but the Palouse soil should contain considerably more root material in the surface 10-inch layer than the Helmer soil. The total quantity of organic materials including top growth and roots available for these two soils at a depth of 10 inches, the depth sampled for organic carbon determinations, although apparently greater for the Palouse than for the Helmer soil may not be sufficient, however, to account for the fact the humus content of the Helmer soil is only about two-thirds as large as that of the Palouse soil.

The nature of the root system in contributing to the humus supply is a factor worthy of consideration. The fine, uniform root system of the Palouse soil may favor more rapid decomposition than the larger, coarser roots in the Helmer soil. More important than the nature of the root system in the formation of humus is the composition and particularly the nitrogen content of the organic materials from which humus is formed. The fact that the nitrogen content of both the humus and the surface organic residue of the Helmer soil is considerably lower than that of comparable substances in the Palouse soil has already been mentioned. In a recent publication from this laboratory (15) it was pointed out that the formation of humus from plant residues added to Palouse silt loam is directly influenced by the nitrogen content of the residues and the amount of available nitrogen present in the soil. The evidence presented there offers convincing proof that the humus formed in the soil has a definite carbon-nitogen ratio regardless of the quantity of carbonaceous material that is available for decomposition. More carbon was shown to be dissipated by CO_2 evolution in the transformation of low-nitrogen plant residues than that in the transformation of high-nitrogen plant residues, such as alfalfa hay, or of low-nitrogen plant residues supplemented with available nitrogen. Although the more suitable moisture regime for microbial activity, the lower root content, and the larger fungus population of the Helmer soil may be contributory to the lower humus content of this soil as compared with the Palouse soil, it is not unlikely that one of the principal reasons for this difference

is the comparatively low nitrogen content of the coniferous tree residues from which the humus in the Helmer soil is derived, rather than the difference in the total amounts of plant residues annually returned to these two soils. This point, however, remains to be verified by further investigation.

SUMMARY

Microbial analyses were made at various times of the year at depths of 0 to 0.5, 0.5 to 4, and 4 to 10 inches in one area of virgin Helmer silt loam and in two areas of virgin Palouse silt loam developed from identical parent materials under similar climatic conditions. The pH values, oxidation-reduction potentials, and moisture contents of the soil samples obtained at the various times were also determined.

A decided variation in total numbers of microbes occurred during different seasons. Microbial peaks were obtained in spring, especially in April, and in late fall and early winter. Minima occurred in July and August and also in February. The same trend was manifested at the different depths sampled.

The numbers of microbes decreased sharply with depth. On the average, the microbial population in the surface 0.5 inch layers was from three to four times as large as that in the 4–10-inch layers. The three soils yielded similar results in this respect.

The Helmer soil supported the smallest total microbial population, the smallest number of bacteria, and the largest number of fungi. The total microbial population in the two Palouse soils did not vary greatly, but the Palouse soil at Troy, Idaho, contained somewhat larger numbers of actinomyces and fungi, particularly in the two lower depths, than did the Palouse soil at Pullman, Washington. The actinomyces population was much larger than the fungus population and did not vary greatly in the three soils.

The aerobic cellulose-decomposing bacteria and anaerobic nitrogen-fixing bacteria in these soils were relatively few in numbers and fluctuated so much at various times that no significant trend with respect to effects of season or native vegetation was indicated. The *Azotobacter* species was not present in any of the soils at any time.

The pH values of the Helmer soil were lower than those of the Palouse soil in the same locality, probably because of the peculiar nature of the organic residue returned to the soil. The pH values of the Palouse soil at Troy were slightly lower than those of the Palouse soil at Pullman, probably on account of the more humid climate in the Troy area.

The oxidation-reduction potentials were lower in the surface 0.5-inch layer of the three soils than in the two underlying layers. No consistent difference in the oxidation-reduction potential values of the three soils was obtained, and no correlation was apparent between these values and the differences in microbial activity in the various soils.

The observed differences in total microbial population and numbers in specific groups of microbes are assumed to be the result of differences in mois-

ture, reaction, and especially the nature of the organic food supply. Both the humus and the surface organic residue of the Helmer soil had less nitrogen, wider carbon-nitrogen ratios, and more H_2SO_4 insoluble carbon than did the comparable materials of the Palouse soils.

Determinations of the top growth of grass vegetation on the Palouse soil indicated that the amount of dry matter produced by this vegetation and consequently returned to the surface of the soil is about 0.7 tons per acre annually. This, according to available data, is about half as much dry matter as is annually returned to forest soils by the average top growth of forest vegetation. The average weights of oven-dried root material in the surface 10-inch layer were approximately 7 tons and 4.7 tons an acre for the Palouse and Helmer soils respectively.

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BOOK REVIEWS

Studies on Wheat Grown Under Constant Conditions. By H. L. VAN DE SANDE-BAKHUYZEN. Food Research Institute, Stanford University, California, 1937. Pp. xvi + 400, tables 57, figs. 27. Price $4.00.

This volume represents another addition to the series of contributions that have come from the Food Research Institute. These contributions have broadened our outlook on the present and potential food resources of the world.

In undertaking the work dealt with in this treatise, the authors set themselves a clearly defined task. As is noted in the directors' preface:

> This book is a contribution in a field hitherto but little cultivated—the physiology of plants grown under constant conditions. The investigations upon which it is based were undertaken in connection with early studies at the Food Research Institute upon the forecasting of crop yields from the weather, in which it became clear that some of the correlations between the weather at various stages of a crop's growth and the size of the crop could not be explained on the basis of existing knowledge regarding the physiology of growth.

The contents of the book are divided into seven parts, entitled, respectively: The Growth Curve in Annual Plants; Methods and Materials; General Growth Features; Dry Weight and Moisture Content of the Different Organs; Dry Weight and Moisture of the Standard Plant; Nitrogen and Carbon of the Organs; and Nitrogen Metabolism in Relation to Growth and Development. A bibliography and an index are also included in the book.

The physiologist and the agronomist will find much in this book that will fill gaps in the earlier information about the growth of wheat and, in a sense, about the growth of plants in general. Economists, as well as plant physiologists, will gain a clear conception of the limiting factors in the production of our cereal crops.

Catalysis. By GEORG-MARIA SCHWAB. Translated by Hugh S. Taylor and R. Spence. D. Van Nostrand Company, Inc., New York, 1937. Pp. xi + 357, tables 38, figs. 38. Price $4.25.

The translator—Hugh S. Taylor—notes that

> Developments in the field of catalytic reactions by no means suffered to the same extent as conditions in the economic world. When the time came to issue the volume in English it was found necessary to supplement the original text by copious additions from the recent literature. These were supplied both by the author and the translators.

The author's purpose in writing the book is indicated in the preface. Here the author says:

> The significance of catalysis in the field of chemistry is being brought more and more to our attention, encouraged by the development of technology on the one hand and of scientific

biology on the other. The perfection of the indispensable physiochemical foundations of the catalysis has, in general, kept pace with the consequent increasing necessity for a scientific treatment of the subject, and chemical kinetics particularly, in its present state of rapidly advancing development, affords a generously proportioned substructure. It is true that new, as yet unsolved, and more deeply penetrating problems are now emerging in growing numbers from behind older questions which have been cleared up, but it is precisely for this reason that an attempt at a comprehensive consideration of catalysis from the standpoint of chemical kinetics promises some reward.

The book is made up of 19 chapters, accompanied by an author index and a subject index. The topics dealt with in the several chapters are as follows: Historical Introduction; General Introduction; Catalysis of Homogeneous Gas Reactions, I. Simple Reactions; Catalysis of Homogeneous Gas Reactions, II. Chain Reactions; Homogeneous Catalysis in Solution, I. The Concept of Intermediate Steps; Homogeneous Catalysis in Solution, II. Fundamentals of Ion Catalysis; Homogeneous Catalysis in Solution, III. The Catalytic Salt Effect; Homogeneous Catalysis in Solution, IV. The Influence of Solvent; Negative Catalysis in Solution; Heterogeneous Catalysis. General Introduction; Adsorption; Kinetics of Heterogeneous Catalysis; Activation and the Mechanisms of Catalysis; Selective Catalysis and Poisons; The State of a Catalyst; Mixed Catalysts, Supported Catalysts and Promoter Action; Heterogeneous Chain Reactions; Catalysis in Solid Systems; and Micro-Heterogeneous and Bio-Catalysts.

Catalysis will be enthusiastically received by many workers in the specialized field of chemistry. The facts and interpretations presented by the author should be particularly helpful to the biochemist. The book should find wide application and should prove serviceable to the student and teacher.

Statistical Methods. By GEORGE W. SNEDECOR. Collegiate Press, Inc., Ames, Iowa, 1937. Pp. xiii + 341, tables 133, figs. 22. Price $3.75.

The present work is one of the interesting projects of the Collegiate Press, Inc., at Ames, Iowa. It serves to remind one of the rapid strides made by abstract and applied science in the midwestern and northwestern states. The rule of thumb methods of the pioneers have been replaced in large measure by the more exact methods of the investigator and statistician. To quote the author:

> Like all other sciences, statistics is in a stage of rapid evolution. During the last 20 years new discoveries have swiftly succeeded each other, fruitful syntheses have been effected, novel modes of thought have developed and a whole series of brand new statistical methods have been marketed. The biologist who has not been able to keep abreast of the progress of statistics finds himself a bit confused by the new ideas and technical terms. It is thought that he will welcome a statement of them in a form that will not require too much distraction of his attention from necessary professional duties.

Aside from the introduction, the book is made up of 16 chapters, a general index, and an index of symbols. The chapters are named, respectively: Experiments on Attributes; An Experiment Designed to Compare Measure-

ments of Individuals; Sampling from a Normally Distributed Population; An Experiment Designed to Compare Two Groups; Short Cuts and Approximations; Linear Regression; Correlation; Large Sample Theory; Enumeration Data with Multiple Degrees of Freedom; Experiments Involving More than Two Groups of Measurement Data. Analysis of Variance; Analysis of Variance with Two Criteria of Classification; Two Variates in Two or More Groups. Covariance; Multiple Regression and Covariance; Curvilinear Regression; Individual Degrees of Freedom; and Labor Samples of Enumeration Data. Binomial and Poisson Distributions.

In these days of local and national planning, the statistical methods discussed by the author should prove very helpful in connection with studies related to biological and other trends. Certainly, our tools are now more perfect for measuring various probabilities. The present work should find a place on the reference shelf of the teacher and investigator.

Biological Laboratory Technique. By J. BRONTË GATENBY. Chemical Publishing Co. of N. Y., Inc., New York, 1937. Pp. vii + 130, ills. 8. Price $3.00.

The author tells us in the preface that "This book has been written in a practical manner for two classes of persons, first the University teacher or student who may desire a short and simple introduction to the most recent and established practice in microtomy, and secondly, the amateur who may wish to make a small laboratory of his own, and is unaware that a good part of modern laboratory research is carried out with the simplest apparatus."

The book is made up of nine chapters, designated as follows: Introduction. Laboratory Apparatus; Treatment of Living Cells, Saline Media, Vital Staining; Fixed and Stained Smears; Microchemical Tests in Smears; Whole Mounts; Fixation Methods; Paraffin, Dioxan and N-Butyl Alcohol and Celloidin Imbedding; Stains and Staining; and Notes for Histology and Embryology Students, and Addenda.

Despite the fact that other laboratory manuals relating to biological technique are available, the present work has much to be said for it from the point of view of the arrangement of the subject matter, the clearness and conciseness of statement, and the reference to the more recent contributions to biological laboratory technique.

Economics of Agriculture. By A. P. VAN DER POST. Central News Agency, Limited, Johannesburg, South Africa, 1937. Pp. xxvii + 663, tables 67, figs. 20.

Interest in agricultural economics is being stimulated by important political and social trends. Here and there, economic and fiscal policies have undergone far-reaching changes—partly because of the growth of economic nationalisms. Imports and exports of agricultural products have been modified in response to political pressure, new political and party alignments, and the emphasis now

being laid on economic self-sufficiency. The author is well aware of these facts, for he notes in his preface:

> The difficulties which agriculture has experienced since the Great War have caused attention more and more to be focused on the problems of that great industry. The economic aspect of these problems, however, is but imperfectly understood and the attention bestowed on them has consequently in many respects been misdirected, solutions being sought in uneconomic rather than economic action. Moreover in the treatment of economics, on the one hand, and of agriculture, on the other hand, the fundamental interdependence of all economic activity and, therefore, of all forms of human endeavor and industry is all too often ignored. The result is neglect of agriculture in the treatment of economics and *per contra* of economics in the treatment of agriculture and, if so far as practical policy is concerned, failure to consider the possible effect of measures taken in one sphere on other spheres of economical endeavor.

The nature of the material dealt with by the author is clearly shown by the titles of the 22 chapters of which the book is made up. The several chapters are designated, respectively: Introduction: Agriculture, Economics, Agricultural Economics and Farm Management; The Origin, Rise and Development of Agriculture; The Factors of Production; The Combination of the Factors of Production in Agriculture; The Personal Factor in Agricultural Production; Capital as a Factor of Agricultural Production; Land as a Factor of Agricultural Production (a) Character; Land as a Factor of Agricultural Production (b) Size of Holding; Agricultural Regions, Systems and Practices; The Economic Basis of Rural Development (a) General Economic Policy: the Trek to Town; The Economic Basis of Rural Development (b) Principles to be observed in Land Settlement; The Economic Basis of Rural Development (c) Irrigation Settlements; The Distribution of the Agricultural Income; The Marketing of Agricultural Produce (a) Value, Demand and Supply, Money, Price; The Marketing of Agricultural Produce (b) Meaning of Marketing, Methods, Middlemen, Marketing Costs; The Marketing of Agricultural Produce (c) Co-operation and Sale through One Channel; International Trade (a) Origin and Nature, Foreign Exchange, Advantages and Disadvantages, Importance to Agriculture; International Trade (b) Import Duties, Protection, Free Trade and Agriculture; Trade Cycles and Agriculture; Farm Relief; Agricultural Credit; Some Economic Aspects of the Agriculture of the Union of South Africa.

It is obvious that the author has drawn extensively on information from various sources. He makes his acknowledgments to material of American, Australian, Dutch, English, French, German, South African, South American, and New Zealand origin. Because of the wide range of his studies and interpretations, his deductions are all the more interesting. The reader will find in the book much that is enlightening and entertaining as well.

Crop Management and Soil Conservation. By JOSEPH F. COX AND LYMAN E. JACKSON. John Wiley & Sons, Inc., New York, 1937. Pp. xvii + 610, tables 36, figs. 199.

The wide publicity now being given to conservation, in general, and to soil conservation, in particular, has made many persons conservation-conscious. As a nation, we may be fairly charged with sins of omission as well as of commission in dealing with our land resources. Much of the soil organic matter has been dissipated. Sheet erosion and gully erosion have depreciated the value of many millions of acres, and the plant-food resources of our soils have been diminished to a point where in many areas crop production is no longer profitable. The federal government and the states are now trying to repair some of the damage that has been done and to restore the fertility of the land wherever this may be practicable. Hence, *Crop Management and Soil Conservation* is a particularly timely contribution on the subject.

The following statement in the preface, made by the editors and authors, is indicative of their interpretation of their task:

> It is the primary object of this book in dealing with specific crops to present in a simple way the major operations that will enable the grower to grow and market his crops successfully. Practices that are effective in reducing the cost of production, improving crop qualities, maintaining fertility, and marketing efficiently are given particular emphasis. The solid and lasting achievements of recent years in developing a national program directed toward the balancing of crop production and the conservation of soils are given an important place in this book.

The book is divided into two parts containing, altogether, 34 chapters, an appendix, and an index. The several chapters are entitled: Balancing Crop Production and Maintaining Fertility; Surveying Crop Production from the Farm Management Standpoint; The Nature and Use of Crop Plants; The Growth and Maturing of Crop Plants; The Nature of Soils; Protecting our Soil from Erosion; Manuring, Fertilizing, and Liming Field Crops; Growing Best-Adapted Crops; Securing the Best Crop Varieties; Growing Seed on the Farm; Growing Crops in Rotation; Preparing Seed Beds, Planting and Cultivating Crops; Harvesting and Storing Crops; Marketing Crops and Federal Programs for Agriculture; Controlling Crop Diseases; Controlling Insect Pests; Controlling Weeds; Planning Improvements in Crop Management and Soil Conservation Programs for Specific Farms; Corn Growing; Wheat and Rye Growing; Oats, Barley, Buckwheat and Flax Growing; Sorghum Growing; Growing Soybeans and Cowpeas; Growing the Clovers; Alfalfa and Sweet Clover Growing; Growing Lespedeza and Other Legumes; Growing Grasses for Hay and Pasture; Managing Pastures; Growing Annual Grasses and Legumes for Hay, Pasture, Green Manuring, and Cover-Crop Purposes; Potato Growing; Field-Bean Growing; Sugar-Beet Growing and the Growing of Other Root Crops; Growing Special Field-Truck Crops; and Growing Home Food and Feed Crops.

This book will be particularly useful to teachers of vocational agriculture. It should prove to be of value also to the general reader, the progressive farmer, and to teachers in our agricultural colleges.

Potash Deficiency Symptoms. By OSKAR ECKSTEIN, ALBERT BRUNO, AND J. W. TURRENTINE. Verlagsgesellschaft für Ackerbau M. B. H., Berlin, 1937. Pp. xii + 235, ill. 54.

For many years the technologist has been trying to define the symptoms related to definite deficiencies in plants. Much progress has been made in this field in recent years. The scientific definitions have reached a point where the landowner may take advantage of the information that has been made available to the end that he might learn from the crop itself what may be lacking in the soil. The present volume is a valuable contribution on the subject of plant deficiency symptoms with particular reference to potash.

In the foreword, written by the noted plant physiologist Gabriel Bertrand, the following is noted:

> On passing from the realms of theory to the practical consideration of the problem, in other words from the laboratory to the field, complications arise. The soil is an exceedingly complex structure the nature of which is ill defined. It not only contains mineral substances of varying composition and properties but is also populated by innumerable animal and vegetable micro-organisms, which compete with the crop for the available supply of potash. On the other hand climatic factors beyond man's control such as light, heat, and above all dew, mist and rain, influence the yields to a considerable extent and tend sometimes to mask the effect of the fertilizers applied. It is, however, very difficult for agriculturists to ascertain whether their soils contain a sufficient supply of available "potash," and it is to assist them in solving this important problem that Messrs. Eckstein, Bruno and Turrentine have published this volume which I have great pleasure in sponsoring.

The first part of the book contains a discussion of the general symptoms of potash deficiency. The second part deals with potash deficiency symptoms of various cultivated crops. The deficiency symptoms as manifested by the different parts of the plant are fully discussed. A discussion is also included on the secondary effect of potash deficiency. Confirmation is offered of deficiency symptoms in maize by chemical tests. Similar reference is made to other cereals, to fruit trees, and to grape vines.

The illustrations are extremely valuable as indicative of potash deficiency. The color plates are excellent and will unquestionably prove most helpful to producers as well as to teachers and investigators. The text is given in three languages; namely, German, French, and English.

Energiequellen der Welt. By RUDOLF REGUL. Hanseatische Verlagsanstalt, Hamburg, Berlin, 1937. Pp. 78.

The major topics dealt with in this publication include an introduction to energy economics and statistics. The first part deals with the upbuilding and developments in the use of energy in the world. The second part deals with the materials employed in the development of energy for various purposes. Such topics as sources of energy, the utilization of energy, the consumption of energy, and the international exchange of energy carriers are considered by the author.

The subject discussed in this treatise is of a particularly timely character. The statesman, as well as the economist and industrialist, is intimately concerned with the resources of coal, mineral oils, water power, and wood. The general recognition of the rapid depletion of some of our energy resources has stimulated a search for new sources of energy. The statistical information offered by the author should prove helpful to all students of economics and of international trade.

Rothamsted Experimental Station Report for 1936. Gibbs & Danforth, Ltd., St. Albans, England, 1937. Pp. 294. Price 2/6.

The cumulative value of the long-term experiments conducted at the Rothamsted Experimental Station at Harpenden is apparent to every student of soils and soil management. The present report covers the activities for 1936, supplementing the interesting and helpful data which appeared in earlier reports. A short statement concerning this particular report—prepared at the Rothamsted Station—follows:

The Annual Report of the Rothamsted Experimental Station fills a special place in the literature of science applied to agriculture. It reaches research workers in soil science and plant nutrition all over the world, and is of special interest to scientific workers, advisory officers and students in this country. It outlines the present position of the various investigations on soil and fertilizer problems conducted at the Station, and gives in full the yield figures for 1936 obtained from some 120 experiments carried out at Rothamsted, Woburn and numerous commercial farms in various parts of England.

An important section summarises the results obtained in experiments on soil cultivation during the last 11 years. Contrary to the widely accepted view the results obtained up to the present indicate that under the conditions prevailing at Rothamsted, yields are not greatly dependent on the particular cultivation methods used, so long as the work is done at the right time. These trials must be continued but the figures already available are worth careful study. A preliminary discussion of the effects of fallowing on the yields of wheat on Broadbalk Field brings out the striking difference of behaviour between the starved and the fully manured plots. When the yield is poor, fallowing produces a large increase in yield; in the presence of nitrogenous manures the effect is much less and may even be harmful in the first year following. The benefit due to fallow appears to be only of one year duration as measured in the wheat crop. Experiments on the incorporation of raw straw with an accompanying dose of artificials show that handled in this way straw has so far produced much the same effect as dung or Adoo Compost. Other sections of importance deal with experiments on dried poultry manure and the effect of fertilisers on sugar beet.

Long period surveys of the work of certain departments have been a feature of recent reports. This year the summaries deal with Field Experiments, Fermentation, Insecticides, and Entomology.

JACOB G. LIPMAN